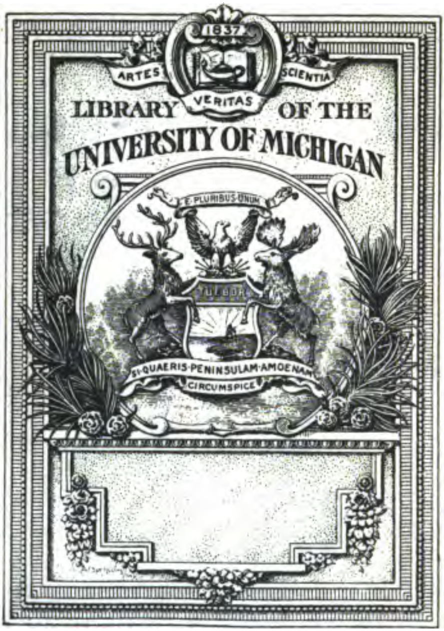
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# THE
# Elements of Navigation

*A short and complete explanation of the standard methods of finding the position of a ship at sea and the course to be steered*

DESIGNED FOR
THE INSTRUCTION OF BEGINNERS

BY

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*Illustrated*

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TO

CAPTAIN J. W. MILLER

COMMANDING THE NAVAL MILITIA

NEW YORK

## PREFACE

THE need of a short, simple, and yet comprehensive book on the art of navigating a ship has led the author to undertake the preparation of the present work. The extant treatises on the subject are of two kinds: first, introductory and simple, but incomplete; and, second, exhaustive, but incomprehensible to the beginner. The aim of this book is to instruct the beginner, leading him step by step from the first operations to the perfection of the art as found in the Sumner method. The instructions have been made as terse as possible, and yet the author believes that clearness has not been sacrificed. Fundamental principles have been explained, but no attempt has been made to elucidate the higher mathematics of the subject. Students who have tried to learn navigation from books like Captain Lecky's inimitable *Wrinkles in Practical Navigation*, which is addressed to navigators only, or from

Bowditch's *American Navigator*, which is only for mathematicians, will, it is hoped, appreciate this little book. The explanations of the uses of the tables and the *Nautical Almanac* are a new feature in a work of this kind.

The author has consulted the following authorities: Bowditch's *American Navigator*, Norie's *Epitome of Navigation*, Raper's *Practice of Navigation*, Lieutenant Sturdy's *Practical Aid to the Navigator*, Lecky's *Wrinkles in Practical Navigation*, Qualtrough's *Sailor's Handy Book*, Patterson's *Navigator's Pocket Book*, Proctor's *Half Hours with the Stars*, and Towson's *Deviation of the Compass*. He desires to express his indebtedness to all of these works, but most especially to those of Captain Lecky and Lieutenant Sturdy.

# CONTENTS

# ELEMENTS OF NAVIGATION

THE reader of this book is cautioned that no words are wasted in it. Facts are stated once and not repeated. Explanations are given but once. The student must master each fact, each explanation, and each process before proceeding to the next.

The books and instruments needed in the study of navigation are mentioned in the proper places. The beginner, having mastered this book, will be prepared to enter upon the actual practice of navigation, but will naturally have much to acquire from experience.

A navigator's library should contain such works as those mentioned in the Preface, and also treatises on the waters to be navigated, such as the *American Coast Pilot*, Findlay's *North and South Atlantic*, and others.

A complete list and description of all lights and beacons on the Atlantic and Gulf coasts of the United States can be obtained at any nautical-instrument house free.

The Nautical Almanac can be purchased for 50 cents.

It is presumed that the student knows what latitude and longitude are, and that he can add, subtract, multiply, and divide degrees, minutes, and seconds, and hours, minutes, and seconds, and can work with decimal fractions.

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Navigation is the art of finding the geographical location of a vessel at sea, the most direct course to be steered in pursuit of the voyage, and the distance to be made.

There are two branches of the art—dead-reckoning and observation.

Navigation by dead-reckoning consists in actually measuring the courses and distances sailed by the ship, and from them computing the distance and direction from the port left and to the port sought.

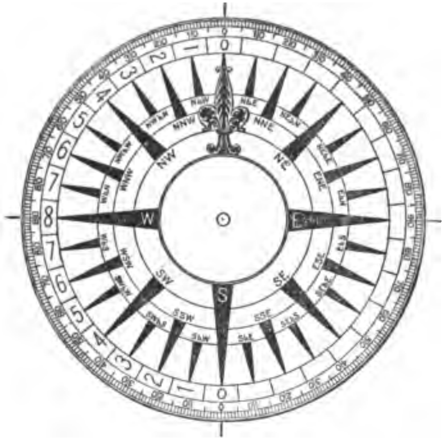
Navigation by observation consists in measuring the angular altitude of celestial bodies above the horizon, and computing

the position of the ship by the application of astronomical and mathematical laws.

The problems of dead-reckoning are solved by plane trigonometry; those of observation by spherical trigonometry. But as the trigonometrical data are all provided in the tables printed in epitomes of navigation, the mariner is not required to be acquainted with any higher mathematics than simple arithmetic.

The instruments used in dead-reckoning are the compass, log, and lead-line. The compass shows the direction in which the ship is travelling; the log measures the speed or the distance. The lead is used when on soundings to measure the depth of water and ascertain the character of the bottom. These data, referred to the chart, throw valuable light on the question of the ship's position. Approaching a coast in thick weather, or on a dark, cloudy night, the lead is the navigator's main reliance.

In addition to these instruments, the navigator requires for all his work accurate charts of the waters which he is traversing and their coasts. Charts issued by governments are more trustworthy than those



COMPASS-CARD, SHOWING POINTS AND DEGREES

published by private firms, which have not the resources of nations.

The mariner's compass is the first instrument which the navigator must know. It is presumed that any person who reads this book has seen a compass; therefore it is not described. The card is the part which concerns the learner at this point. Its circumference is divided into 32 equal parts, called points. Each point has a

name, and these names the student must learn to repeat in regular order from north around by way of east and back to north, thus:

North, north-by-east, north-northeast, northeast-by-north, northeast, northeast-by-east, east-northeast, east-by-north, east, east-by-south, east-southeast, southeast-by-east, southeast, southeast-by-south, south-southeast, south-by-east, south, south-by-west, south-southwest, southwest-by-south, southwest, southwest-by-west, west-southwest, west-by-south, west, west-by-north, west-northwest, northwest-by-west, northwest, northwest-by-north, north-northwest, north-by-west, north.

This is called "boxing the compass." Any intelligent person can easily discover the system on which the points are named. North, south, east, and west are called the cardinal points; northeast, southeast, southwest, and northwest are the intercardinal points. Each cardinal point is 8 points away from the nearest cardinal, and 4 points away from the nearest intercardinal.

In navigation all courses are reckoned from the north-and-south line of the com-

pass, which is called the meridian. Thus north-northeast, south-southeast, north-northwest, and south-southwest are 2-point courses. East and west are 8-point courses.

TABLES SHOWING THE NAMES OF POINTS AND QUARTER-
EACH COURSE, AND THE ANGLE MADE BY EACH WITH

| North | | Points | |
|---|---|---|---|
| N.¼E. | N.¼W. | ¼ | 2° 48′ 45″ |
| N.½E. | N.½W. | ½ | 5° 37′ 30″ |
| N.¾E. | N.¾W. | ¾ | 8° 26′ 15″ |
| N.-by-E. | N.-by-W. | 1 | 11° 15′ — |
| N.-by-E.¼E. | N.-by-W.¼W. | 1¼ | 14° 3′ 45″ |
| N.-by-E.½E. | N.-by-W.½W. | 1½ | 16° 52′ 30″ |
| N.-by-E.¾E. | N.-by-W.¾W. | 1¾ | 19° 41′ 15″ |
| N.N.E. | N.N.W. | 2 | 22° 30′ — |
| N.N.E.¼E. | N.N.W.¼W. | 2¼ | 25° 18′ 45″ |
| N.N.E.½E. | N.N.W.½W. | 2½ | 28° 7′ 30″ |
| N.N.E.¾E. | N.N.W.¾W. | 2¾ | 30° 56′ 15″ |
| N.E.-by-N. | N.W.-by-N. | 3 | 33° 45′ — |
| N.E.¾N. | N.W.¾N. | 3¼ | 36° 33′ 45″ |
| N.E.½N. | N.W.½N. | 3½ | 39° 22′ 30″ |
| N.E.¼N. | N.W.¼N. | 3¾ | 42° 11′ 15″ |
| N.E. | N.W. | 4 | 45° — — |
| N.E.¼E. | N.W.¼W. | 4¼ | 47° 48′ 45″ |
| N.E.½E. | N.W.½W. | 4½ | 50° 37′ 30″ |
| N.E.¾E. | N.W.¾W. | 4¾ | 53° 26′ 15″ |
| N.E.-by-E. | N.W.-by-W. | 5 | 56° 15′ — |
| N.E.-by-E.¼E. | N.W.-by-W.¼W. | 5¼ | 59° 3′ 45″ |
| N.E.-by-E.½E. | N.W.-by-W.½W. | 5½ | 61° 52′ 30″ |
| N.E.-by-E.¾E. | N.W.-by-W.¾W. | 5¾ | 64° 41′ 15″ |
| E.N.E. | W.N.W. | 6 | 67° 30′ — |
| E.N.E.¼E. | W.N.W.¼W. | 6¼ | 70° 18′ 45″ |
| E.N.E.½E. | W.N.W.½W. | 6½ | 73° 7′ 30″ |
| E.N.E.¾E. | W.N.W.¾W. | 6¾ | 75° 56′ 15″ |
| E.-by-N. | W.-by-N. | 7 | 78° 45′ — |
| E.¾N. | W.¾N. | 7¼ | 81° 33′ 45″ |
| E.½N. | W.½N. | 7½ | 84° 22′ 30″ |
| E.¼N. | W.¼N. | 7¾ | 87° 11′ 15″ |
| East. | West. | 8 | 90° — — |

Southeast-by-south is a 3-point course. The student should examine the compass card and see how many courses of each kind there are, bearing in mind that there

**POINTS, NUMBER OF POINTS AND FRACTIONS OF POINTS IN THE MERIDIAN.**

| South | | Points | |
|---|---|---|---|
| S.¼E. | S.¼W. | ¼ | 2° 48′ 45″ |
| S.½E. | S.½W. | ½ | 5° 37′ 30″ |
| S.¾E. | S.¾W. | ¾ | 8° 26′ 15″ |
| S.-by-E. | S.-by-W. | 1 | 11° 15′ — |
| S.-by-E.¼E. | S.-by-W.¼W. | 1¼ | 14° 3′ 45″ |
| S.-by-E.½E. | S.-by-W.½W. | 1½ | 16° 52′ 30″ |
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| S.S.E. | S.S.W. | 2 | 22° 30′ — |
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| S.E.-by-S. | S.W.-by-S. | 3 | 33° 45′ — |
| S.E.¾S. | S.W.¾S. | 3¼ | 36° 33′ 45″ |
| S.E.½S. | S.W.½S. | 3½ | 39° 22′ 30″ |
| S.E.¼S. | S.W.¼S. | 3¾ | 42° 11′ 15″ |
| S.E. | S.W. | 4 | 45° — — |
| S.E.¼E. | S.W.¼W. | 4¼ | 47° 48′ 45″ |
| S.E.½E. | S.W.½W. | 4½ | 50° 37′ 30″ |
| S.E.¾E. | S.W.¾W. | 4¾ | 53° 26′ 15″ |
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| E.S.E.¾E. | W.S.W.¾W. | 6¾ | 75° 56′ 15″ |
| E.-by-S. | W.-by-S. | 7 | 78° 45′ — |
| E.¾S. | W.¾S. | 7¼ | 81° 33′ 45″ |
| E.½S. | W.½S. | 7½ | 84° 22′ 30″ |
| E.¼S. | W.¼S. | 7¾ | 87° 11′ 15″ |
| East. | West. | 8 | 90° — — |

is nothing greater than an 8-point course. After a careful study of the points the student should be able to answer with facility all such questions as these:

How many 1-point courses are there? 2-point? 3-point, etc.? Name them. How many points is it from E.S.E. to S.W.-by-S.? How many points from N.E.-by-E. to W.-by-S.? How many points from E.-by-S. to E.N.E.? What points are 3 points away from W.-by-N.?

Again, a square-rigged vessel beating to windward will sail a course 6 points off the wind. The navigator must be able to answer all such questions as these: Heading N.N.E. on the port tack, how will the vessel head when she has come about? (The answer will require a count of 12 points.) Ship heading S.-by-W. close hauled on the starboard tack, what direction is the wind?

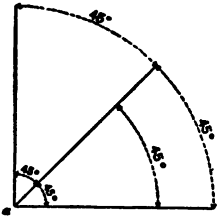
Until the student is master of the points of the compass and their relations he should go no further. When he has learned them, he must acquaint himself with the half and quarter points as set forth in the preceding table.

The next step is to learn the angle which

each course makes with the meridian. Meridians are imaginary lines running north and south from pole to pole and used for the determination of longitude. The meridian of the compass is so called because it is the north-and-south line, and may be regarded as coinciding with the imaginary meridian on which the ship is located. If an actual north-and-south line were ruled on the surface of the sea, and you started your ship off to the northeast, you would at once see that she was sailing on a course that made an angle of 45° from the meridian. But your compass will tell you the same thing.

The circumferences of all circles, no matter how large or how small, are divided into 360 equal parts called degrees, and all angles are measured by these. A single glance at the accompanying diagram will illustrate this. The angles at *a* do not increase in size because their boundary lines are prolonged. If these lines were prolonged till they reached the apparent sky the angle at their juncture would be the same size—45°. A degree, therefore, is $\frac{1}{360}$ of the circumference of any circle, no matter what size. Do not forget this

important fact. If you divide the 360° of the compass-card by its 32 points, you will learn that 1 point equals 11° 15'. By adding 11° 15' for each additional point, you will learn that 2 points equal 22° 30', 3 points 33° 45', 4 points 45°, 5 points 56° 15', 6 points 67° 30', 7 points 78° 45', and 8 points 90°. Sailing-vessels cannot be steered closer than a quarter of a point, and for their navigation a quarter-point may be roughly estimated as 3°. Steamers can be steered more closely, and their courses are set in degrees. A course of this kind is expressed as so many degrees east or west from the meridian, thus: N. 47° E., S. 36° W.



QUARTER-CIRCLE

## VARIATION

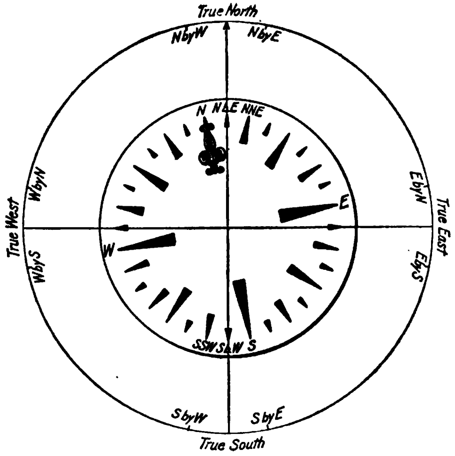
The north point of the compass indicates true or geographical north at only a few places on the globe. At all other places it points a little to one side or the other of north. This error is called variation of the compass.

It is caused by the fact that the magnetic north and south poles of the earth do not coincide with the true or geographical poles. The former is several hundred miles south of the geographical pole, and the latter several hundred miles north. The needle is perfectly true; it points right at the magnetic north pole. But that pole is not the north end of the earth's axis.

In navigating a vessel it is necessary to make allowance for this variation. The amount of allowance and its direction are indicated on the charts. On large charts, such as that of the North Atlantic, will be found irregular lines running from the top to the bottom of the paper, and having beside them such inscriptions as 10° W., 15° W. This means that along this line the variation of the compass from true north is 10° W., 15° W. There are certain lines

which have no variation, and here no allowance is to be made. On small charts, such as that of New York Bay, the variation is shown by the compass-card printed on the chart. The north point of it will be found slewed a little to the eastward or westward of a meridian line, and near it will be seen an inscription, such as "Variation 11° W. in 1892." Now let us see how this variation affects the compass aboard ship, and how we are to allow for it, so that we shall know exactly which way we are going, even when the compass does not tell the truth.

Let the outer circle represent the sea horizon, the inner circle the compass-card. The variation is one point westerly. Hence the north point of the compass points to the north-by-west point of the horizon, and the south point of the compass to the south-by-east point of the horizon. In other words, standing at the centre and looking towards the circumference, you find that every point on the compass is one point to the left of the proper place. If your compass says you are sailing north, you are really sailing N.-by-W. If it says south, you are going S.-by-E. If it says




VARIATION OF COMPASS

east, you are going E.-by-N. Hence we get these rules:

*To correct a compass course.*—When the variation is westerly, the true course will be as many points to the *left* of the compass course as there are points of variation. When the variation is easterly, the true course will be as many points to the *right* of the compass course.

Conversely, having ascertained the true

course between two places, you must construct the proper compass course by applying the variation, and the rule, therefore, is:

*To convert a true course into a compass course.*—Variation westerly, compass course to the *right* of true course; variation easterly, compass course to the left.

To illustrate for yourself, draw a large circle and mark off the compass points on it. Now cut out of stiff paper a miniature compass-card with the points marked. Fasten it by a pin through its centre to the centre of your large circle. By turning the north point of the compass-card as many points to the right or left of the fixed or true north as you have variation east or west, you will see at once how each separate point on the compass is affected.

## DEVIATION

In addition to the magnetism of the earth, which affects all compasses alike, no matter how situated, we have to contend with deviation, which is a local error caused by the influence of neighboring iron or

steel. In ships built of either of these metals this influence is very great, and no compass aboard such a ship is ever quite correct, except possibly on one or two courses. As the compass-card does not turn with the ship when her course is altered, it follows that the mass of metal of which she is composed assumes new relations to the needles of the compass, and that, as a result, the error caused by deviation must change whenever the course is changed.

This is what makes the problems arising from deviation extremely troublesome, and it makes it necessary to ascertain the amount of error on each course. It is customary in merchant vessels to use what are called compensated compasses. Before leaving port an expert, called a compass adjuster, ascertains the amount and direction of the deviation of each compass on the principal courses, and endeavors, by placing magnets in the deck, to counteract it. A certain amount of error always remains. This is noted by the adjuster, who will furnish the master of the ship with a table of residual errors, showing the amount and direction of the devi-

ation remaining on each course after adjustment.

Do not place great faith in these tables, for deviation changes in different latitudes, and the residual errors will be altered.

It is not possible to treat the subject of deviation exhaustively in an elementary work of this kind. The student will be shown how to ascertain his deviation on each course and to make the necessary corrections. This is the only trustworthy method of dealing with this difficulty of navigation, and for the purposes of simple practice it is all that the beginner needs to know.

But no man is fit to take entire charge of the navigation of any vessel who does not know all about the nature and causes of errors of the compass. Therefore the student who aspires to mastery of the art of navigating should read Chap. II., Part I., and Chap. XII., Part II., of Lecky's *Wrinkles in Practical Navigation*, Evans's *Elementary Manual for Deviation of the Compass*, and Towson's *Deviation of the Compass*.

Some important cautions may be given

here. Keep all iron and steel as far from your compasses as possible.

Bear in mind that magnetic influence will not be stopped by placing anything between the compass and the iron or steel. It will pass through a stone wall.

If you use compensated compasses, see that the magnets, once placed by the adjusters, are let severely alone. They should never be touched.

Make it an invariable rule to ascertain the deviation of the compass on every course steered by the methods hereinafter explained, and to correct the course accordingly.

Bear in mind when ascertaining your deviation that it is good only for that one course. If your ship is heading E.S.E. and you find the deviation to be 10° E., it will be something else the moment you alter the course to E.-by-S., or even E.S.E.½E.

Bear in mind in taking bearings to apply the deviation according to the direction of the ship's head. For instance, you are lying at anchor. Your compasses have just been adjusted. The ship's head points N.W.-by-N. The table of errors says that on that course the deviation is one point

easterly. Directly on your starboard beam is a light-house. You wish to get its bearing. The compass says it bears N.E.-by-E. But you have one point easterly deviation. Hence the correct compass bearing is E.N.E.

The corrections for deviation are applied in exactly the same way as those for variation. Use the same rules.

Large vessels carry more than one compass. One of these is situated above the deck and as far away from local influences as possible. It is called the standard compass, and the ship is navigated by it.

*To set a course by a standard compass.*—Stand by the standard yourself and station a man at the steering compass. Order the helm to port or starboard till the ship is precisely on her course by the standard. At that instant blow a whistle (or give any other preconcerted signal), and the man at the steering compass notes the direction of the ship's head according to it. The course which he gets is the one to be given to the helmsman.

## HOW TO FIND THE DEVIATION

*In port.* — Take the standard compass ashore, and set it up in a spot which is precisely in line between the regular station of the compass aboard ship and some distant object visible from said station. The bearing of the distant object by the standard compass will now be the correct compass (or magnetic, as it is usually called) bearing, unless you have been stupid enough to set up your compass near iron or steel.

Now take the compass back aboard ship and set it up in its regular place. The ship must now be swung around so as to bring her head successively on each of the 32 points of the compass. At each heading take the bearing of the distant object before selected. The differences between the bearing obtained ashore and those now obtained will be the deviations for the successive headings of the ship. Your results should be tabulated thus:

| Magnetic bearing | Course | Compass bearing | Deviation |
|---|---|---|---|
| S. 42° W. | N. | S. 43° W. | 1° W. |
| S. 42° W. | N.-by-E. | S. 40° W. | 2° E. |
| S. 42° W. | N.N.E. | S. 49° W. | 7° W. |
| S. 42° W. | N.E.-by-N. | S. 38° W. | 4° E. |

And so on to N.-by-W. Your deviations, of course, will not vary thus from east to west. These figures are used simply to give practice in the application of the rules for the correction of deviation and variation. If the compass bearing is to the right of the correct magnetic bearing the deviation is westerly, and if to the left, easterly.

*By the sun.* — Some compasses are provided with a shadow pin, which sets up in the centre of the instrument. The sun casts a shadow of this pin, which falls on the card at the bearing opposite to that of the sun. Thus, if the shadow falls S.S.W., the sun bears N.N.E. You can thus get the compass bearing of the sun.

A better arrangement is the azimuth attachment. This is an arm with an upright at each extremity. It is arranged so that these uprights are directly opposite one another outside the circumference of the compass. Each upright is slit down the centre. In one is stretched a perpendicular hair, while the other is fitted with an eye-piece and a colored shade to deaden the rays of the sun. By sighting through the eye-piece and the hair one can get an

accurate bearing of the sun or any other object.

AZIMUTH ATTACHMENT

Having obtained the *compass* bearing, you consult Burdwood's or Davis's Azimuth Tables, which give the *true* bearing of the sun for every four minutes in the day. Burdwood's is for latitudes from 60° to 30°, and Davis's thence to the equator. Take a compass bearing of the sun and note the time. Ascertain from Burdwood or Davis the true bearing. The difference between this and your compass bearing will be the total error of the compass, embracing both variation and deviation. The chart gives the variation. Take it from the total error and you have the deviation left.

EXAMPLE

| | |
|---|---|
| Sun's true bearing at 3.15 P.M......N. 150° W= | S. 30° W. |
| Variation by chart .............................. | 10° W. |
| Correct compass (magnetic) bearing............ | S. 40° W. |
| Bearing by ship's compass.................... | S. 27° W. |
| Deviation........................ | 13° E. |

You may ask why it is not sufficient to know the total error of the compass with-

out ascertaining the deviation. The answer is that you may hold one course till you have changed your variation. If you do not know the deviation, you must now take another azimuth.

Another method of using the sun is by amplitudes, observed at rising or setting. The true bearings are given in Table 39, Bowditch. In using this, as well as Burdwood or Davis, you must know the latitude of your ship and the declination of the sun, which is obtained from the nautical almanac for the day. The peculiarity of the table of amplitudes is that it gives the bearings as so many degrees N. or S. of E. and W. Thus with latitude 15° N., declination 6° N., you get from the table an amplitude of 6.2, which at sunset would be read W. 6° 12′ N., the true bearing of the sun.

Any other heavenly body whose declination is not greater than the range given in either the azimuth or amplitude tables can be used exactly as the sun is. A method of finding the true bearing of any celestial body, no matter how great its declination, will be given in the proper place.

Leeway is, of course, not an error of the compass; but as it has to be considered in the correction of compass courses in dead-reckoning, it is convenient to introduce the subject here. A vessel sailing on a wind, or even with the wind abeam, will slide off to leeward more or less. Consequently her actual course will not be that indicated by compass, even when corrected for variation and deviation.

*To find the leeway.* — Experienced sailors can estimate the leeway by the angle between the vessel's wake and her keel. A good plan, however, is to heave the log, then bring the line to the centre of the compass, and its angle with the vessel's course will show the amount of leeway.

*To correct for leeway.* — Leeway on the starboard tack is the same as westerly variation. Leeway on the port tack is the same as easterly variation. The corrections are made in the same way. A glance at the diagram will make this clear. The vessel heading N.E. on the starboard tack and

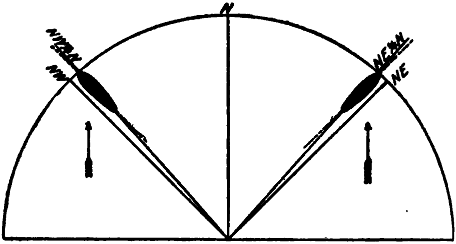


DIAGRAM OF LEEWAY

making a quarter-point of leeway is actually going N.E.¼N. The vessel on the port tack heading N.W. and making a quarter-point of leeway is really going N.W.¼N.

A good point to remember is this: leeway on the port tack and westerly variation or deviation are opposed to one another, and the same is true of leeway on the starboard tack and easterly error. For example, you have a quarter-point westerly variation, no deviation, and a quarter-point leeway on the port tack; the leeway and variation counterbalance one another, and the compass course is the true course. The form given in the following examples

for practice is that used in computing a vessel's dead-reckoning :

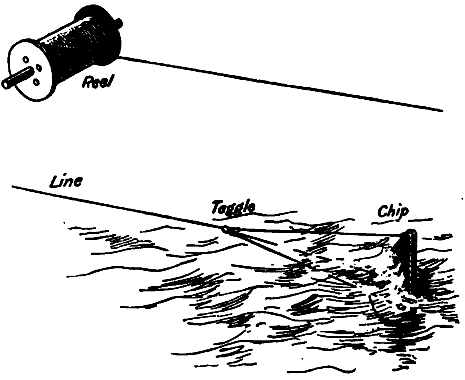
| Compass course | Leeway | Variation | Deviation | True course |
|---|---|---|---|---|
| S.W.-by-W. | ¼pt. Port | ½pt. W. | ¼pt. W. | S.W.½W. |
| E.-by-S. | 3° Starb. | 16° W. | 10° E. | E.¼S. |
| N.N.E.½E. | ¼pt. Star. | 1 pt. E. | 2 pts. W. | N.-by-E.¼E. |
| S. 42° E. | 6° Port | 20° W. | 25° E. | S. 31° E. |
| S. 33° W. | 3° Starb. | 5° E. | 3° W. | S. 32° W. |

The student should set himself many problems of this kind for practice, and should not attempt to go further with this subject until he has mastered this one matter. Endless difficulty will otherwise be the result. A good method of study is to use the turning-card mentioned under the head of variation. But you must in the end be able to work without it. For instance, in the first example proceed thus: Port tack and westerly variation are opposed; that leaves a quarter-point westerly, which added to a quarter-point westerly (deviation) gives a half-point westerly correction; a half-point to the left of S.W.-by-W. is S.W.½W. In the second example, starboard-tack leeway and westerly variation add, giving 19° westerly correction; subtract 10° and you have 9° westerly left;

9°, or about three-quarters of a point, to the left of E.-by-S. is E.¾S.

## THE LOG

There are two kinds of logs, the chip log and the patent or taffrail log. The principal parts of the chip log are the chip, the reel, the line, and the toggle. A second-glass is used for measuring the time.




CHIP LOG AND REEL

The chip is a triangular piece of wood, rounded on its lower edge and ballasted with lead to make it ride point up. The toggle is a little wooden case into which a peg, joining the ends of the two lower lines of the bridle, is set in such a way that a jerk on the line will free it, causing the log to lie flat so that it can be hauled in. The inboard end of the line is wound around the reel. The first 10 or 15 fathoms of line from the log-chip are called "stray line," and the end of this is distinguished by a mark of red bunting 6 inches long. Its purpose is to let the chip get clear of the swirl under a vessel's counter before reckoning begins.

The knots, as they are called, are distinguished by running pieces of fish-line through the strands to the number of one, two, three, etc. A piece of white bunting, two inches long, marks every two-tenths of a knot. This is because the run of a ship is recorded in knots and tenths.

A new log-line should be soaked in water a few days before marking, and always before leaving port you should soak your line and then see that the marks are all at the proper distances.

The log-glass, in appearance like an hour-glass, measures 28 seconds. For high rates of speed, a 14-second glass is used, and then the number of knots shown by the line must be doubled. In damp weather a watch is better than a sand-glass.

The principle of the chip log is that the length of a knot bears the same ratio to the nautical mile (6086 feet) as the time of the glass does to the hour. Hence we get this proportion: As the number of seconds in an hour is to the number of feet in a mile, so is the number of seconds in the glass to the number of feet in the knot.

$$3600 : 6086 :: 28 \text{ sec.} : x$$
$$x = 47 \text{ feet } 4 \text{ inches.}$$

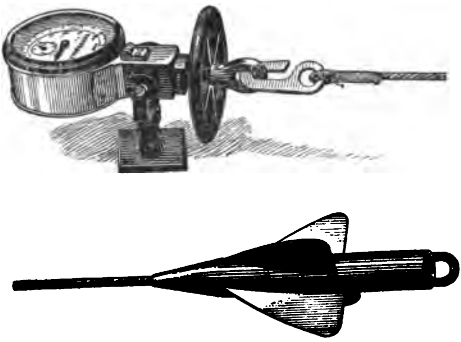
The speed of the ship is recorded in the log-book in knots and tenths of a knot.

*How to heave the chip log.*— Have an assistant to hold the glass. See that all the sand is in the bottom. Heave the log-chip well out to leeward from the stern, and hold the reel so the line will run freely. As soon as the stray line is out call "Turn," and the assistant must turn the glass quickly and start the sand running. The instant the sand has passed down

the assistant must call "Stop," and you check the line. Note the number of knots and tenths and haul in.

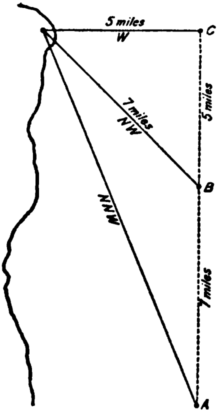
The chip log should be hove every hour. If the speed varies between hours it must be estimated, or the log hove again.

The patent or towing log consists of a dial, a line, and a rotator of screw-propel-



PATENT OR TOWING LOG

ler form. The action of the water on the rotator, which is at the end of the line and thrown overboard, causes the line to make

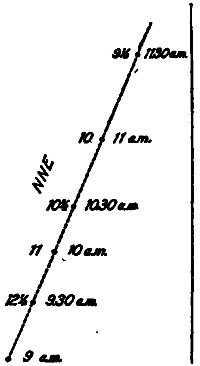



COASTWISE BEARINGS

the observed object at the second bearing.

In the diagram the ship at A heading north finds the light bearing N.N.W., 2 points off her course. At B she finds it bears N.W., 4 points off. The log makes the distance from A to B 7 miles. This will be *almost* the exact distance of the light from the ship at B. The commonest form of this problem is that used at positions B and C, with the object 4 points off the course and exactly abeam. This is known as the bow-and-beam bearing. The navigator will find cases in which the other form is convenient. This method should be practised continually, as it is the standard method in coastwise navigation. It is also valuable in establishing a final position with reference to the land when about to go to sea.

*How to use compass, log, and lead in a fog.*—Take a piece of tracing-paper and rule a meridian on it. Take casts of the lead at regular intervals, noting the time at which each cast is taken, and the distance logged between each two. The compass shows the course. Now rule a line on the tracing-paper in the direction of your course. Measure off on it by the scale of miles of your chart the distances run between casts. Opposite each cast note the time and the depth ascertained. It is a good thing to add also the character of the bottom. Now lay your tracing-paper down on the chart, which can be seen through it, in the neighborhood of the position you believed yourself to be in when you made the first cast. If your chain of soundings agrees with those on the chart right under your course, all is



CHAIN OF SOUNDINGS

right. If not, move the tracing-paper about, keeping the meridian line due north and south, till you find the place on the chart that does agree with you. That is where you are. You will not find two places where you can get that chain of soundings on the same course and at the same distances.

This is the *only* method by which a ship's position can be found with any certainty on soundings in thick weather. There is no excuse whatever for the man who runs his vessel ashore, if he has not tried this.

## DEAD RECKONING

To ascertain the position of a ship at sea by keeping account of the courses and distances which she sails, we proceed on the theory that small sections of the surface of the earth are flat. The whole matter then resolves itself into the solution of right-angled triangles. A single glance will show the student that any of the courses ruled on the diagram chart unite with the parallels and meridians in forming

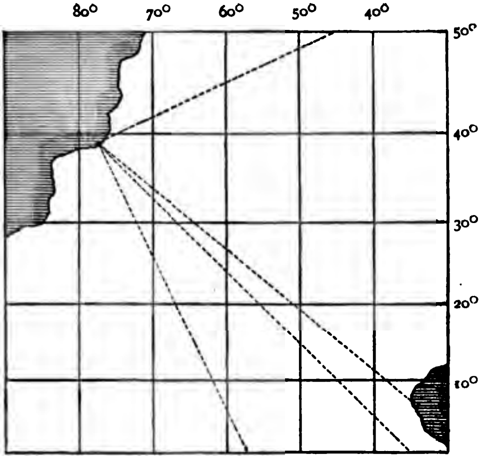



DIAGRAM CHART

series of right-angled triangles. The only cases in which no such triangles exist are those of sailing due east and west or due north and south.

The problems to be solved in sailing on the open sea out of sight of land are these: Having left a known point and sailed so many miles in such and such direction, what latitude and longitude have we arrived at, and what are the course and dis-

tance thence to our point of destination?

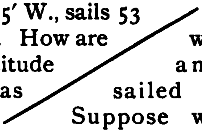
If you are sailing due north or south, the problem is extremely simple. Suppose your position at noon to-day is lat. 41° 15′ N., long. 40° W., and up to noon to-morrow you sail 280 miles north (true). It is obvious that the longitude will remain unchanged. The latitude will be 280 minutes, or 4° 40′, farther north. That 4° 40′ is called the difference of latitude, and in this case it is obviously to be added to to-day's latitude, because we have been increasing our latitude. The ship's position at to-morrow noon, then, is lat. 45° 55′ N., long. 40° W.

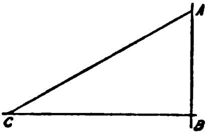
Hence we learn that the distance by which a ship changes her latitude north or south is called difference of latitude.

In sailing due east or west, however, the matter is not so simple, because only on the equator are a nautical mile and a minute of longitude the same thing. But if we have a table giving us the number of miles in a degree of longitude at every distance north or south of the equator (which means in every latitude), we can easily find the longitude. For instance, a ship in lat. 42° N. sails true east 100 miles; how much

does she alter her longitude? A degree of longitude in lat. 40° measures 44.59 miles. She changes her longitude by 2° 10.8′ or 2° 10′ 48″—a tenth of a minute being 6″.

The number of *miles*, then, which a ship makes east or west is called *departure*, and it must be converted into degrees, minutes, and seconds in order to find the difference of longitude.

But nine times out of ten a ship sails a diagonal course. Suppose a vessel in lat. 40° 20′ N., long. 60° 15′ W., sails 53 miles S.W.-by-W.½W. How are we to find her new latitude and longitude? She has sailed a course like this:  Suppose we draw a perpendicular line to represent a meridian, and a horizontal one to represent a parallel. Then we shall have the triangle ABC, in which the line AC represents the distance and direction, while




the angle at A is the angle of the course with the meridian. If now we can ascertain the length of AB, or the distance by which

she has gone to the south, we shall have the difference of latitude; and if we can get the length of the line BC, we shall have the departure and from it the difference of longitude. From these two factors we get the new latitude and longitude.

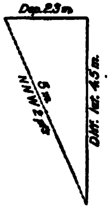
This is a simple problem in trigonometry, but no navigator need know trigonometry, because Tables I. and II. of Bowditch solve all possible problems of this kind for him, and he needs only arithmetic.

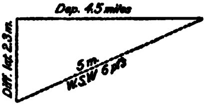
The complete Navigation Tables can be purchased separate from the rest of the work, under the title *Useful Tables*, for $1.25.

Table I. is marked at the top with the different courses from ¼ point up to 4 points. In three adjoining columns are found distance, difference of latitude, and departure, marked Dist., Lat., and Dep. If you are sailing on any particular course, say N.N.E., you go to the table for 2-point courses, look in the distance column for the distance you have made by your log, and opposite to that distance you will find your diff. lat. and dep.

At 4 points diff. of lat. and dep. become equal, because the course is precisely half

way between no points and 8 points. On any course *less* than 4 points diff. lat. is greater than dep., because you go more north or south than east or west. On any course *greater* than 4 points dep. is greater than diff. lat., because you go more east or west than north or south. And the relations of the two elements are simply reversed, as may be seen by the diagrams. In a 2-point course, the diff. lat. is the same as the dep. in a 6-point course, the complement of a 2-point course. Hence, in using the tables, as soon as you have a course over 4 points, you begin at the last page of the tables and read *up* from the bottom, noting that while *dist.* remains in the same place, lat. and dep. are reversed.




Suppose you have sailed 28 miles N.-by-W.¼W. Opposite 28 in the dist. column under 1¼-point courses you find diff. lat. 27.2 miles and dep. 6.8 miles.

Suppose you have sailed 40 miles E.-by-N. Under 7-point courses you find (read-

ing from the bottom up) opposite dist. 40, diff. lat. 7.8, dep. 39.2.

Table II., Bowditch, contains the same elements worked for courses in degrees. You should now be prepared to work such examples as these:

A ship leaving lat. 36° 15′ N., long. 47° 48′ W., sails S.E.-by-E. 78 miles. Required the diff. lat., the dep., and the new lat.

*Ans.* Diff. lat. 43.3, dep. 64.9, new lat. 35° 31′ 42″ N.

(Bear in mind that a tenth of an hour or a degree is 6 minutes; a tenth of a mintue, 6 seconds.)

A ship leaving lat. 28° 15′ S., long. 43° 18′ E., sails 49 miles N.W. What are the diff. lat., dep., and new lat.?

*Ans.* Diff. lat. 34.6 miles, dep. 34.6, new lat. 27° 40′ 24″ S.

A ship leaving lat. 1° 10′ N., long. 16° 5′ W., sails S.S.E. 168 miles. Give same elements.

*Ans.* Diff. lat. 155.2 miles, dep. 64.3 miles, new lat. 1° 25′ 12″ S.

A ship leaving lat. 15° 15′ N., long. 121° 31′ E., sails N. 63° E. 64 miles. Give same elements.

*Ans.* Diff. lat. 29.1, dep. 57, new lat. 15° 44′ 6″ N.

The full rule for finding the new lat. is as follows:

When the old lat., known as *lat. left*, and diff. lat. are both N. or both S., add them; when one is N. and the other S., subtract the less from the greater, and the remainder, named N. or S. after the greater, will be the new lat., known as lat. *in*.

The next step is to find the diff. long., and from it the new, or long. in. The proportions of right-angled triangles are such that all you have to do is to obey the following rule:

Find the mid. lat. between that of yesterday and that of to-day. Go to the page in Table II., marked with the number of degrees of this mid. lat. which you have just found, and seek in the *diff. lat.* column for the amount of your *dep.* Opposite to it in the *dist.* column will be the figures indicating the number of *minutes* in the *diff. long.*

*Example:* A ship in lat. 36° 15′ N., long. 52° 18′ W., sails N.E.-by-N. 60 miles; required the lat. and long. in.

Table I., under the head of 3-point courses, gives for 60 miles diff. lat. 49.9 miles, dep. 33.3. The lat. in is, therefore, 37° 4′ 54″ N. To find the mid. lat. add

the lat. left and the lat. in, and divide by 2. Take the nearest degree as your answer. In this case the mid. lat. is 36° 39′ 57″, and as that is nearer 37° than 36° we take the former. Now turn to the page for 37° in Table II. Apply the dep. 33.3 in the lat. column; the nearest you can come to it is 33.5, opposite which in the dist. column is 42, which means that in lat. 37° a dep. of 33.5 miles will equal 42′ diff. long. Long. left was 52° 18′ W. We have made 42′ diff. long. to the eastward, thus diminishing our westerly longitude. We subtract 42′ from 52° 18′ W., and get 51° 36′ W. as our long. in.

This process of working out the latitude and longitude is called *middle latitude sailing*, and by it the ordinary problems of dead-reckoning are solved. The cases which present themselves in the actual practice of navigation are three in number.

*Case I.*—Course and distance sailed being given, to find the diff. lat. and dep.

*Case II.*—The lat. and long. left and the course and distance being given, to find the lat. and long. in.

*Case III.*—The latitudes and longitudes of two places being given, to find the course and distance between them.

Cases I. and II. have been explained, except as to sailing true east or west, which is called *parallel* sailing. Here there is no diff. lat., and the lat. in is the mid. lat. To find the diff. long. apply the distance sailed, which in this case is also the departure, in the lat. column, and opposite it in the dist. column will stand the number of minutes in the diff. long.

*To solve case III.*—Subtract the less latitude from the greater, and reduce the remainder to minutes. Do the same with the two longitudes. Find the mid. lat. Go to the page in Table II. marked with the number of degrees in the mid. lat., and seek the diff. long. in the dist. column. Opposite to it in the lat. column will be the dep. Now seek in Table II. for the page where the diff. lat. and the dep. stand beside one another in their respective columns. The required dist. will stand opposite in the dist. column, and the course either at the top or bottom of the page, according as diff. lat. or dep. is the greater.

In using Tables I. and II., if the dist., lat., or dep. in your problem happens to be larger than those contained in the table, you can obviate the difficulty by dividing all your

elements by 10, because the relations of all the parts of a right-angled triangle one-tenth the size of yours will be just the same if you reduce all three sides to one-tenth. For instance, you have diff. lat. 304′; dep. 2694 miles. Divide both by 10 and you have 30.4 and 269.4, both of which are in the tables. With those you can find one-tenth of your distance, which take out and multiply by 10. The angles all remain the same, so the course is all right as it stands.

*Example:* A ship in lat. 42° 3′ N., long. 70° 4′ W., is bound for St. Mary's, lat. 36° 59′ N., long. 25° 10′ W. What are the course and distance?

| | |
|---|---|
| Lat. left ..........42° 03′ N. | Long. left ....70° 04′ W. |
| Lat. sought.......36° 59′ N. | Long. sought..25° 10′ W. |
| Diff. lat.......... 5° 04′ | Diff. long.....44° 54′ |
| Reduced to minutes = 304 | Reduced to minutes = 2694 |
| Middle lat........39° 31′. | |

As the tables do not run beyond 300 miles, we take one-tenth of 2694 (the diff. long.), 269, and under 40° with this number in the dist. column we get 206.1 dep. out of the lat. column. Now we look for a place where the diff. lat. is 30.4 and the dep. 206.1. As we are working with one-tenth of the dep., we must do the same with 304, the diff. lat., or, in other words, put a decimal mark before the 4,

making it 30.4. We find under the head of 7½ points diff. lat. 30.7, dep. 206.7, and opposite them the dist. 209. This is one-tenth of the real distance, 2090 miles. As the diff. lat. was southward and the diff. long. eastward, the course must be S. 7½ points E., or E.¾S.

## EXAMPLES FOR PRACTICE

*(From Norie's Epitome)*

Required the course and distance from the Cape of Good Hope, lat. 34° 22′ S., long. 18° 24′ E., to St. Helena, lat. 15° 55′ S., long. 5° 45′ W.

*Ans.* Course N. 50° W., dist. 1717 miles.

Required course and distance from Pernambuco, lat. 8° 4′ S., long. 34° 53′ W., to Cape Verde, lat. 14° 45′ N., long. 17° 32′ W.

*Ans.* Course N. 37° E., dist. 1720 miles.

A ship from lat. 2° 5′ N. and long. 22° 30′ W. sails W.S.W. 256 leagues (a league= 3 miles). Required her present lat. and long., and her course and dist. to St. Ann's Island, lat. 2° 15′ S., long. 43° 38′ W.

*Ans.* Lat. 2° 49′ S., long. 34° 20′ W., course N. 86° W. dist. 559.6 miles.

Excellent practice may be had by laying off courses and distances on charts, and then

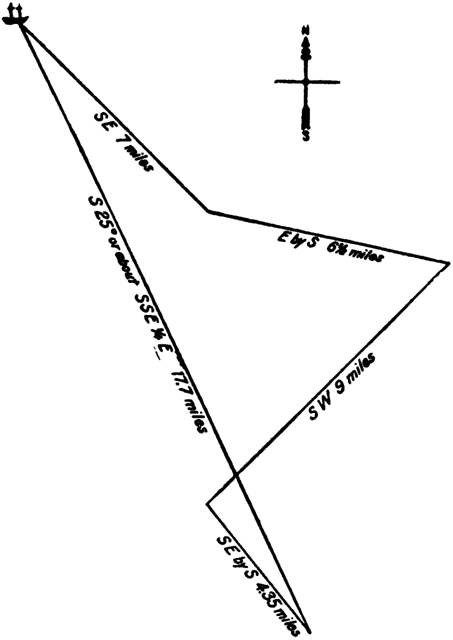
working out the same by computation to see how near your two results will agree.

### WORKING A TRAVERSE

If a ship sailed for 24 hours on one course, the student would now be ready to work out her latitude and longitude by dead-reckoning. But vessels usually change the course several times in the course of a day's run, and as the reckoning is only computed once a day — at noon — it becomes necessary to have a method of obtaining the result of several courses. This is called working a traverse, and it is the culmination of dead-reckoning.

Suppose a vessel to start from Sandy Hook Lightship, lat. 40° 28′ N., long. 73° 50′ W., and sail in 24 hours S.E. 7 miles, E.-by-S. 6¼ miles, S.W. 9 miles, and S.E.-by-S. 4.35 miles; where would she be at noon on the second day? The diagram shows us that she would be 17.7 miles about S.S.E.¼E. of the lightship. The method of calculating such a compound course is called working a traverse, and is as follows:

Write out the various courses with their corrections for variation, leeway, and deviation, and the distance run on each. In




TRAVERSE COURSE FROM SANDY HOOK LIGHTSHIP

four columns, headed respectively N., S., E., W., put down the diff. of lat. and dep. for each course. Add together all the northings, all the southings, all the eastings, all the westings. Subtract to find the difference between northings and southings, and you will get the whole diff. lat. The difference between eastings and westings will give the whole dep.

With the whole diff. lat. and whole dep., seek in Table II. for the page where the nearest agreement of lat. and dep. with your figures can be found. The number of degrees at the top or bottom of the page (according as diff. lat. or dep. is greater) will give you the *course made good* and distance.

Find the lat. in, as already explained.

Find the long. in, as already explained.

*Example:* A ship in lat. 31° 15′ N., long. 68° 30′ 15″ W., sails by compass 36 miles E.-by-S., with 1 pt. W. var., ¼-pt. E. dev., ½-pt. port-tack leeway; 22 miles S.S.E. with same variation, ½-pt. E. dev., ¼-pt. starboard-tack leeway; 28 miles S. by E. with same variation, ¼ W. dev., ¼-pt. port-tack leeway; and 31 miles S. with ¾-pt. W. var., ½-pt. E. dev., and ¼-pt. port-tack leeway. Required the course and distance made good and the new lat. and long.

| Comp. course | Variation | Deviation | Leeway | True course | Dist. | N. | S. | E. | W. |
|---|---|---|---|---|---|---|---|---|---|
| E.-by-S. | 1 pt. W. | ¼E. | ½pt. Port | E.¾S. | 36 | .. | 5.3 | 35.6 | .. |
| S.S.E. | 1 pt. W. | ½E. | ¼pt. Starb. | S.S.E.¾E. | 22 | .. | 18.9 | 11.3 | .. |
| S.-by-E. | 1 pt. W. | ¼W. | ¼pt. Port | S.S.E. | 28 | .. | 25.9 | 10.7 | .. |
| S. | ¾pt. W. | ½E. | ¼pt. Port | S. | 31 | .. | 31 | .. | .. |
| | | | | | | | 81.1 Dif. lat. | 57.6 Dep. | |

*Ans.* Course made good S. 35° E., dist. 99 miles.

Lat. left..............31° 15′ 00″ N.
Diff. lat.............. 1° 21′ 06″ S.
Lat. in................29° 53′ 54″ N.

31° 15′ 00″ N.
29° 53′ 54″ N.
2 ) 61° 08′ 54″
Middle lat........ 30° 34′ 27″

Long. left............68° 30′ 15″ W.
Diff. long............ 1° 07′ 00″ E.
Long. in.............67° 23′ 15″ W.

In this example there is no subtraction of southing and northing, or of easting and westing. Let us suppose a case, however, of a ship beating to the eastward, and forced to run off to the northwest by some accident. Omitting the corrections of the compass course for the sake of brevity, we should have a traverse like this:

| Lat. left, 26° 30′ N. | | Long. left, 48° 25′ W. | | | |
|---|---|---|---|---|---|
| Course | Distance | N. | S. | E. | W. |
| S.S.E. | 12 | .. | 11.1 | 4.6 | .. |
| N.E.$\frac{1}{4}$E. | 16 | 10.7 | .. | 11.9 | .. |
| S.E.$\frac{1}{8}$E. | 14 | .. | 8.9 | 10.8 | .. |
| W.N.W. | 13 | 5.0 | .. | .. | 12.0 |
| | | 15.7 | 20.0 | 27.3 | 12.0 |
| | | | 15.7 | 12.0 | |
| | | | 4.3 | 15.3 | |

Course S. 74° E. Distance, 16 miles.

| | |
|---|---|
| Lat. left....26° 30′ 00″ N. | Long. left.....48° 25′ W. |
| Diff. lat.... 4′ 18″ S. | Diff. long..... 17′ E. |
| Lat. in.....26° 25′ 42″ N. | Long. in......48° 08′ W. |

*Currents.*—In case the ship encounters a known current setting diagonally across the course, multiply the rate of the flow by the number of hours and enter it as distance, and enter the direction as a course.

*Example:* A ship from lat. 36° 15′ S., long. 101° 14′ E., sails in 24 hours 30 miles N.N.W. true, and 68 miles W.$\frac{1}{2}$N. true.

During 12 hours of the day she is in a current setting E.½S. at the rate of 2 knots per hour. Required her course and distance made good.

| Course | Distance | N. | S. | E. | W. |
|---|---|---|---|---|---|
| N.N.W. | 30 | 27.7 | .... | .... | 11.5 |
| W.½N. | 68 | 6.7 | .... | .... | 67.7 |
| E.½S. | 24 | .... | 2.4 | 23.9 | .... |
| | | 34.4 | | | 79.2 |
| | | 2.4 | | | 23.9 |
| | | 32.0 | | | 55.3 |

*Ans.* Course made good, N. 60° W., dist. 64 miles.

HOVE TO

A vessel hove to in a gale comes up towards the wind and then falls off, and her course is a zigzag. To keep her reckoning note how she heads when she has come up as far as she will, and again when she has fallen off to the limit. The point half way between is to be called the course. For instance, she comes up to east and falls off to northeast. The course is east-northeast.

The leeway, variation, and deviation are applied to the course thus ascertained.

Different ships make different leeway, and the navigator must determine its extent by careful observation.

Every time she begins to come up she will go ahead a little. The speed of this progress or "drift" is entered as the rate in knots. The rest of the operation is the same as in working a traverse.

*Example:* A vessel in lat. 33° 14′ S., long. 60° 47′ E., is hove to on the starboard tack. She comes up to E.-by-S., and falls off to E.-by-N.; leeway, 6 points; drift, 2 knots per hour; variation, 22° E.; vessel hove to 24 hours. What is her position at noon of the second day? (See table on page 67.)

## SHAPING THE COURSE

Having ascertained the position of the ship, it becomes necessary to ascertain the course required to sail to reach the port of destination. This may be done by using the chart, if the distance is small and the scale of the chart large. If the distance is considerable and the scale of the chart small, much inaccuracy will follow.

| Comp. course | Leeway | Variation | True course | Dist. | N. | S. | E. | W. |
|---|---|---|---|---|---|---|---|---|
| E. | 6 pts. Starb. | 2 pts. E. | N.E. | 48 | 33·9 | .. | 33·9 | .. |

Lat. left............33° 14′ 00″ S.
Diff. lat............00° 33′ 54″ N.
Lat. in..............32° 40′ 06″ S.

$$\begin{array}{r} 33^\circ\ 14'\ 00'' \\ 32^\circ\ 40'\ 06'' \\ \hline 2\,)\,65^\circ\ 54'\ 06'' \\ \hline 32^\circ\ 57' = 33^\circ \text{ middle lat.} \end{array}$$

Departure......33.9 in lat. 33°
= 40′ diff. long.

Long. left......60° 47′ 00″ E.
Diff. long......00° 40′ 00″ E.
Long. in.......61° 27′ 00″ E.

The course is, therefore, to be found either by mid. lat. or Mercator's sailing.

The course is found by mid. lat., according to the rule laid down in Case III. of dead-reckoning.

If the course is more than 4 points, mid. lat. will give a satisfactory result. But if the course is 4 points or less, owing to the construction of Mercator's charts with their expansion of the degrees to the north or south, error will creep in. Consequently Mercator's sailing must be employed. Mid. lat. is good for shaping any course if it is short, except in high latitudes, where the Mercator method should always be used.

To solve problems in Mercator's sailing the navigator must use Table III. This table contains the meridional parts corresponding to the increases in the charted lengths of the degrees of latitude. These parts are picked out by finding the degrees at the top or bottom of the table, and the minutes at the side. Thus the meridional parts corresponding to 19° 45′ are 1201.4; 9° 36′, 574.9; 29′, 28.8.

*To shape the course and find the distance by Mercator's sailing.*—Find the difference

between the meridional parts corresponding to the lat. in and lat. sought. Call this meridional diff. lat. With the meridional diff. lat. and the diff. long. find the course by searching in Table II. for the page where they stand opposite one another in the lat. and dep. columns. Under this course find the distance opposite the proper (*not* meridional) diff. lat.

*Example:* What are the course and distance from Sandy Hook Lightship, lat. 40° 28′ N., long. 73° 50′ W., to lat. 39° 51′ N., long. 72° 45′ W.?

| | | | |
|---|---|---|---|
| Lat. in | 40° 28′ | Mer. parts | 2644.5 |
| Lat. sought | 39° 51′ | Mer. parts | 2596.2 |
| Proper diff. lat. | 0° 37′ | Mer. diff. lat. | 48.3 |
| Long. in | 73° 50′ W. | | |
| Long. sought | 72° 45′ W. | | |
| Diff. long. | 1° 05′ = 65′ | | |

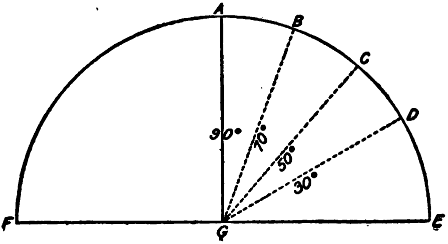
On the page in Table II. which has 37° at the top and 53° at the bottom we find 64.7 and 48.7 opposite one another. This is the nearest agreement to the meridional diff. lat. and the diff. long. that we can find. As the 48.7 is in the right-hand column we must read the table up from the bottom, and this gives us a course of 53°. Our course is, therefore, S. 53° E. Under

53°, applying our proper diff. lat., 37′, in the lat. column we find 37.3, opposite which is our distance, 62 miles.

## NAVIGATION BY OBSERVATION

Navigation by observation is carried on by measuring the altitude of the sun, the moon, or a star, and computing from this and certain other data the latitude or longitude of the ship. The altitude of a celestial body is expressed in terms of degrees and minutes, and is that part of 90° contained between the body and the sea horizon.

An observer standing at the point G in the diagram would see the horizon at E

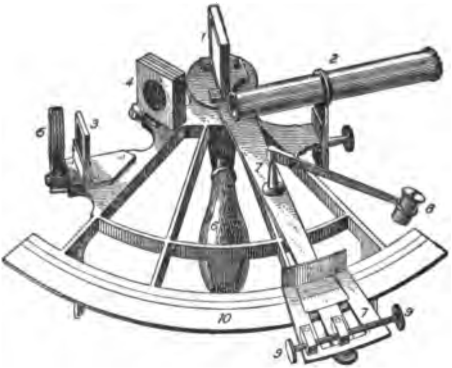


and F, and the apparent sky stretching from one side to the other in a semicircle, or rather hemisphere. Now a circumference of this semicircle is divided, like any other, into 180°. Supposing the sun to rise at E, at D it would be 30° high, at C 50°, at B 70°, and at A, immediately overhead, 90°. Going down the other side its altitude would continually decrease. From this we learn that the altitudes of celestial bodies range from 0 to 90°, for no matter in which direction we face the horizon the arc of the sky from the horizon point opposite us to the zenith, which is the point immediately overhead, will measure 90°.

The first element, then, required in any problem of navigation by observation, is the angular altitude of the celestial body in use. The measurement of this altitude is made by means of the sextant, or an instrument of the sextant family.

The principal parts of the sextant are shown in the accompanying sketch.

The sliding limb (No. 7) has a clamp sliding along the arc (No. 10). A screw passes through this clamp, and by tightening it the sliding limb is held firmly in any position at which it is placed. It can, however,





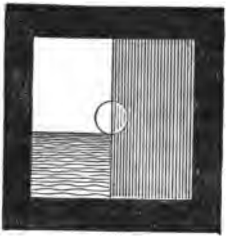
SEXTANT

| | | |
|---|---|---|
| 1. Mirror. | 4. Shade-glasses. | 7. Sliding limb. |
| 2. Telescope. | 5. Back Shade-glasses. | 8. Reading-glass. |
| 3. Horizon-glass. | 6. Handle. | 9. Tangent screw. |
| | | 10. Arc. |

be further moved by very small advances by the use of the tangent screw (No. 9.)

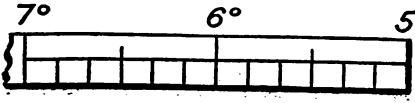
The instrument is held by the handle (No. 6) in the right hand, with the telescope towards the observer's eye. He must now direct the telescope towards that part of the sea which is directly beneath the celestial object to be observed. His line of sight will pass through the horizon-glass. He now moves the sliding limb until the image of the celestial body, reflected by the mirror (No. 1) appears in the horizon-glass. He then tightens the clamp screw,

described above, and by means of the tangent screw (No. 9) moves the sliding limb just a little more, so that the image "kisses" the horizon, which is seen through the transparent half of the horizon-glass. If he can make the image split on the two halves of the glass, as in the cut, the "contact," as it is called, will be all the more accurate. He now reads the angular altitude from the scale on the arc of the sextant by means of the reading-glass. The measurement is shown by a small vernier scale which runs along the oblong opening in the sliding limb.

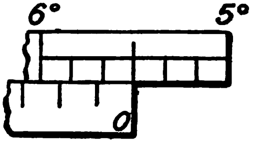


HORIZON-GLASS WITH SUN "KISSING SEA"

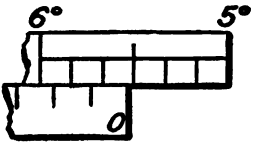
The arc itself is divided into degrees and sixths of a degree in this manner:



The vernier is divided similarly, but its parts represent minutes and sixths of a minute. To read the angle the zero point on the vernier is used as a starting-point. If it exactly coincides with one of the lines on the scale of the arc, that line gives the measurement of the angle; thus, in this case the angle is $5\frac{1}{2}°$, or $5° 30'$.




If, however, you find the zero point has passed a line of the arc, as in the second case shown, your angle is more than $5° 30'$, and you must look along the vernier to the left till you find the point where the lines do coincide. Then add the number of minutes and sixths of a minute shown on the vernier between zero and the point of coincidence to the number of degrees and minutes shown on the arc at the line which the vernier zero has passed, and the sum will be the angle measured by the instrument.



Some instruments have the arc cut to quarters of a degree, or 15′, and a quadrant is cut to thirds of a degree, the vernier showing minutes only. The sextant is the instrument most in use. The student will require some practice before being able to take and read an altitude of the sun, and a great deal before he can do anything with the stars. An hour's practice under an old mariner, however, will do him more good than a hundred pages of book instruction.

Regulate the shade-glasses to suit your eye. Those at the top of the instrument affect the image of the sun only, and serve to deaden its brilliancy. The back shade-glasses are used when the glare on the water is too powerful. You cannot get a good contact with your eyes dazzled.

### ADJUSTMENTS

I. The mirror must be perpendicular to the plane of the instrument. Set the sliding limb at 60°. Hold the sextant face up. Place the eye nearly in the plane of the instrument opposite the apex and look into

the mirror. If the image of the arc in the mirror and the arc itself show in one unbroken line, the adjustment is correct; if the reflected image is lower, the glass leans backward; if it is higher, the glass leans forward. Straighten the glass by turning the screws at its back.

II. The horizon-glass must be perpendicular to the plane of the instrument. Set the zero of the vernier to the zero of the arc. Hold the sextant almost face upward, and look through the sighting-vane and the horizon-glass at the horizon. If the horizon line and its image (seen in the clean and silvered parts of the glass) do not coincide, turn the screw at the back of the glass till they do.

III. The horizon-glass must be parallel to the mirror. Set the zero of the vernier to the zero of the arc. Hold the instrument as in taking an observation, and look at the horizon. If the line and its image in the silvered part of the horizon-glass coincide, the adjustment is correct; if they do not show in an unbroken line, adjust the horizon-glass by turning its screw.

IV. The line of sight of the telescope must be parallel to the plane of the instru-

ment. "Screw in the telescope containing the two parallel wires, and see that they are turned until parallel with the plane of the sextant; then select two stars, at least 90° apart, and make an exact contact at the wire nearest the plane of the instrument, and read the measured angle. Move the sextant so as to throw the objects on the other wire, and if the contact is still perfect, the axis of the telescope is in its right situation and the telescope adjustment is correct. If the images have separated, it shows that the object end of the telescope droops towards the plane of the sextant, and if the images overlap, it proves that the object end of the telescope points away from the plane of the instrument. This will be rectified by the screws in the collar of the sextant. A defect in the telescope adjustment always makes angles too great" (Patterson).

### INDEX ERROR

It is better to let your instrument alone after once adjusting it. If you continually torture it, you will get it hopelessly out of

order. Error remaining after adjustment is called index error. It is found thus: Set the sliding limb at o, hold the instrument perpendicularly, and look at the horizon. Move the sliding limb forward or backward till the horizon line and its image coincide in the horizon-glass. Clamp the sliding limb and read the angle, which is the index error. If zero on the vernier is to the left of zero on the arc, the index error is to be subtracted; if it is to the right, the error must be added. Index error is usually expressed thus: I. E. $1^\circ\ 15'-$; or I. E. $2^\circ\ 8'+$.

## HINTS ON TAKING ALTITUDES

Learn to take a single sight with accuracy. It is a good thing to take the mean of three or four sights when working longitude, but you cannot always do that.

Oscillating the instrument from right to left and back, while taking a sight, will make the image skim the horizon so that you may make sure of the point vertically under it.

When fog obscures the horizon from the

deck, you can sometimes get a new horizon by lowering away a boat.

In rough weather try to get the mean of three or four sights. You thus reduce the amount of error caused by the pitching of the ship.

Ascertain the index error before taking every altitude or set of altitudes. The error is liable to change.

## CORRECTING THE ALTITUDE

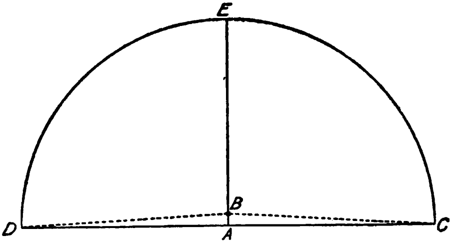
Certain corrections have to be made to all altitudes taken with a sextant. These corrections are for dip of the horizon, refraction, and in the cases of the sun and moon, for semi-diameter.

The altitude used in the computation of the ship's position is that of the centre of the celestial body. As already explained, the sextant gives the altitude of the upper or lower edge.

For navigational purposes we assume that the diameter of the sun equals 32′ of the arc of the sky. Therefore, if you take the altitude of the lower edge you must add 16′, or half the diameter, to get the

altitude of the centre. If you take the altitude of the upper edge, as you might have to do in case the lower one was obscured by clouds, you must subtract 16′. Stars, having no apparent diameter, do not call for this correction.

*Dip of the horizon* means an increase in the altitude caused by the elevation of the eye above the level of the sea. The simplest illustration of this is afforded by the accompanying figure. If the eye is on the




level of the sea at A, it is in the plane of the horizon CD, and the angles EAC and EAD are right angles, or 90° each. If the eye is elevated above A, say to B, it is plain that the angles EBC and EBD are

greater than right angles, or, in other words, that the observer sees more than a semicircle of sky, and hence all measurements made by the sextant are *too large*.

The real cause of this phenomenon is the curvature of the earth's surface, which causes the apparent meeting line of the sea and sky to extend as we go higher up.

The elevation of the eye makes the angle too great; hence the correction for dip is *always subtracted* from the altitude.

Table XIV. gives the corrections for various heights of the eye. It is the navigator's business to measure the height of his eye above the water-line of his ship at such places as he may wish to stand when taking altitudes.

*Refraction* is a curving of the rays of light caused by their entering the earth's atmosphere, which is a denser medium than the impalpable ether of the outer sky. The effect of refraction is frequently seen when an oar is thrust into the water and looks as if it were bent.

Refraction always causes a celestial object to appear higher than it really is. This phenomenon is greatest at the horizon and diminishes towards the zenith, where

it disappears. Table XX. gives the corrections for mean refraction, which are always subtracted from the altitudes. In the higher altitudes, select the correction for the nearest degree.

Avoid taking low altitudes (15° or less) when the atmosphere is not perfectly clear. Haziness increases refraction. If compelled to take a low altitude when there appears to be more than the normal amount of refraction, correct the refraction for the height of the barometer by Table XXI., Bowditch.

The student should now be ready to take and correct all altitudes.

*Example:* At sea, June 27, 1894, observed meridian alt.: ⊙ (this sign stands for the sun; * for a star) 67° 26′ 15″; index error, 1° 15′+; height of eye, 25 feet. Required the T. C. A. (true central altitude).

| | |
|---|---|
| Obs. alt. ⊙ | 67° 26′ 15″ |
| I. E. | 1° 15′ 00″ |
| | 68° 41′ 15″ |
| Semi-diam | 16′ |
| | 68° 25′ 15″ |
| H. of E. correction | 4′ 54″ |
| | 68° 20′ 21″ |
| Refraction | 23.6″ |
| T. C. A. | 68° 19′ 57.4″ |

The chronometer is simply a finely made and adjusted time-piece placed in a box and swung in gimbals, as a compass is, to prevent it from being injured by the motion of the ship.

The care of a chronometer is not essentially a part of the science of navigation, but in practice the navigator has to use and care for his own chronometers, and the author has, therefore, in the latter part of this book, given some suggestions as to the proper treatment of these instruments.

The purpose of the chronometer aboard ship is to register Greenwich time. English and American navigators reckon their longitude east or west from the Greenwich meridian, and, as we shall learn further on, the computation of longitude consists in ascertaining the difference between the time at Greenwich and the time at the ship.

The secondary reason for carrying a chronometer is that the astronomical data contained in the *Nautical Almanac* are all given for the hour of Greenwich noon. The chronometer shows us how many

hours before or after Greenwich noon it is, and thus we are enabled to reduce the data to the time of taking the observation.

It is customary at sea to use a hack watch, set to the time of the chronometer, in taking observations, the chronometer itself never being removed from its place.

Every chronometer gains or loses a little time every day. When in port the instrument is taken to a maker, who regulates it and ascertains its *daily rate* of losing or gaining. On returning it to the owner, the maker furnishes a memorandum stating that on such and such a date the chronometer was so many minutes and seconds faster or slower than Greenwich time, and was losing or gaining so much a day.

The navigator, therefore, must correct the time shown by his chronometer, by adding or subtracting the *daily rate.* It is obvious that the daily rate must be multiplied by the number of days gone since the memorandum was made, and that if it is a losing rate it must be added, and if a gaining rate, subtracted.

*Example:* A chronometer showing 2 hrs., 15 min., 27 sec. on Oct. 11, was 3 min.,

20 sec. slow of Greenwich time on Oct. 1, and its daily rate is 0.8 sec. losing. What is the correct Greenwich time?

*Ans.* Oct. 1 to Oct. 11=10 days; 0.8×10=8.0 sec. loss. On Oct. 11, therefore, the chronom. is 3 min., 20 sec.+8 sec. slow.

| | | | |
|---|---|---|---|
| Chronom. time....... | 2 h. | 15 m. | 27 s. |
| Correction + ... .... | | 3 m. | 28 s. |
| Correct G. T......... | 2 h. | 18 m. | 55 s. |

It is obvious that the correction for daily rate may be computed for many days in advance. The navigator must, however, be sure to remember to correct his chronometer time. If he fails to do so, he will fall into serious, perhaps even fatal errors.

## THE NAUTICAL ALMANAC

The *Nautical Almanac* is a book published by the government, and containing certain data, computed by the national astronomers. Without these data the short and simple astronomical problems of navigation cannot be solved.

The navigator must bear in mind at all times the fact that these data are given for

Greenwich noon. The data concerning the sun are given, under the heading of the month, on two pages. The left-hand page contains the data for *apparent time;* the right-hand page those for *mean time,* The significance of these terms will be explained in the appropriate place. At present it is only necessary to say that when dealing with apparent time, you must take your data from the left-hand page; and when dealing with mean time, from the right-hand. Each page looks like the extract which is reproduced on page 87. The student must not be alarmed by these data. They are much simpler affairs than they appear to be. But he must understand them thoroughly and know how to handle them before proceeding to the simplest observation.

*Declination.*—The declination of a celestial body is its distance north or south of the equator, measured in degrees. In other words, declination is simply celestial latitude. The sky as it appears to the eye, constitutes a sphere surrounding the earth, as in the diagram. The circumference of this sphere must contain 360°. Hence if the sun were immediately over a

*January*, 1895.—AT GREENWICH MEAN NOON

| Day of the week | Day of the month | The Sun's Apparent Rt. Ascension | The Sun's Diff. for 1 hour | The Sun's Apparent Declination | The Sun's Diff. for 1 hour | Equation of Time to be subtracted from Mean Time | Diff. for 1 hour | Sidereal Time or Right Ascension of Mean Sun |
|---|---|---|---|---|---|---|---|---|
| | | h. m. s. | s. | | | m. s. | s. | h. m. s. |
| Tues.. | 1 | 18 47 18.81 | 11.039 | S. 23° 00′ 34.4″ | 12.48″ | 3 46.42 | 1.183 | 18 43 32.39 |
| Wed .. | 2 | 18 51 43.59 | 11.024 | S. 22° 55′ 21.1″ | 13.62″ | 4 14.64 | 1.168 | 18 47 28.95 |
| Thur.. | 3 | 18 56 7.98 | 11.008 | S. 22° 49′ 40.4″ | 14.76″ | 4 42.47 | 1.151 | 18 51 25.51 |
| Frid... | 4 | 19 00 31.97 | 10.990 | S. 22° 43′ 32.6″ | 15.89″ | 5 9.90 | 1.134 | 18 55 22.07 |

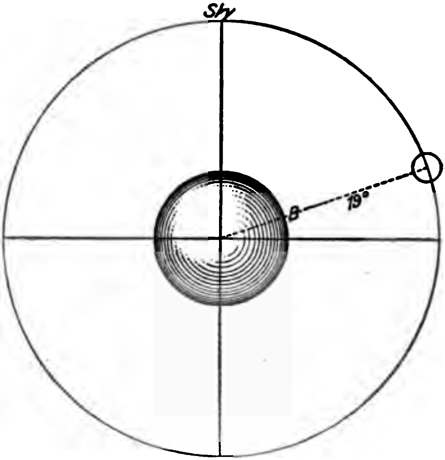



ILLUSTRATION OF DECLINATION

point, say B, it would be in lat. 19° N., or, in other words, its declination would be 19° N.

Declination is, however, a varying quantity. Every school-boy knows that the sun goes south in winter and comes north in summer. This is because the axis of the earth is inclined to the plane of its orbit. If it were perpendicular, the sun would always be immediately over the equator.

The extreme limits of the sun's declination are 23° 27′ 30″ north and south. The former point is reached on June 21, and the latter on Dec. 21. Half way between the former and the latter the sun crosses the line, bound south, as the sailors say. Therefore from June 21 to Sept. 22 or 23 the sun is in north declination, which is constantly decreasing. From the latter date till Dec. 21 it is in south declination, which is always increasing. From Dec. 21 till March 21 or 22 the sun's south declination decreases, and from the latter date till June 21 it is in north declination, increasing. These points are extremely important. By remembering them you can never be in doubt as to whether the declination is north or south.

It is obvious that it is important for the navigator to know the rate at which the declination changes. This is found in the column of the N. A. (symbol for *Nautical Almanac*) adjoining the declination. The first thing to do is to multiply it by the number of hours before or after Greenwich noon as shown by the chronometer, for the declination is given for noon.

Secondly, if the time shown is *after* noon

and the declination is increasing, add the ascertained variation. If the declination is decreasing, subtract the variation. If the time is *before* noon and the declination is increasing, subtract the variation, because the declination will, of course, be larger at noon than at any previous hour. If the declination is decreasing, add the variation.

The result obtained from any of these processes is called the *corrected declination.* The corrected declination is always employed in figuring out the results of an observation.

EXAMPLES

At sea, May 18, 1894, chronom. showed 3 hrs., 15 min., 18 sec. P.M. Required the cor. dec. of ☉.

Dec.....19° 36′ 44.1″ N.
Cor......      1′ 46.4″
Cor. dec. 19° 38′ 30.5″ N.    Hourly diff..32.76″
Chronom. time.. 3 h. 15 m.=3.25 h.
16380
6552
9828
60 ) 106.4700″(1′ 46.4″
60
46

At sea, May 18, 1894, chronom. showed 10 hrs., 30 min., 12 sec. A.M. Required the cor. dec. of ⊙.

| | |
|---|---|
| Dec......19° 36′ 44.1″ N. | Chronom. 10 h. 30 m. 12 s. A.M. |
| Cor...... 49.1″ | 12 h. 00 m. 00 s. noon |
| Cor. dec. 19° 35′ 55.0″ N. | Time before noon. 1 h. 29 m. 48 s. = 1.5 h. |

Hourly diff......32.76″

Time before noon......... 1.50

163800

3276

Correction...............49.1400″

At sea, Jan. 22, 1894, chronom. showed 2 hrs., 45 min., 00 sec. P.M. Required cor. dec. of ⊙.

| | |
|---|---|
| Dec.....19° 36′ 38.7″ S. | Hourly var..34.65″ |
| Cor..... 1′ 35.2″ | Chro. time P.M... 2.75 |
| Cor. dec. 19° 35′ 03.5″ S. | 17325 |
| | 24255 |
| | 6930 |
| | 60)95.2875″(1′ 35.2′ |
| | 60 |
| | 35 |

At sea, Jan. 22, 1894, chronom. showed 9 hrs., 16 min., 15 sec. A.M. Required cor. dec. of ⊙.

| | |
|---|---|
| Dec.... 19° 36′ 38.7″ S. | Hourly var..34.65″ |
| 1′ 35.2″ | Time bef. noon .. 2.75 |
| Cor. dec. 19° 38′ 13.9″ S. | 95.2875″ = 1′ 35.2″ |

## APPARENT AND MEAN TIME—THE EQUATION

Apparent time is that shown by the sun. Mean time is that shown by the clock.

The equation of time is the difference between them.

The earth revolves on its axis once in 24 hours, and theoretically the sun crosses the meridian of any given place at precisely 12 o'clock each day, and it is then noon. As a matter of fact this is not so. The earth does not revolve at a uniform rate of speed, and consequently sometimes the sun is a little ahead of time and again it is behind.

Now you cannot manufacture a clock which will run that way. Its hours must all be of exactly the same length, and it must make noon at precisely 12 o'clock every day. Hence we distinguish clock time from sun time by calling the former mean (or average) time and the latter apparent.

Your chronometer shows G. M. T. (Greenwich mean time).

Your cabin clock should show L. M. T. (Local mean time).

The sun always gives L. A. T. (local apparent time.)

Hence, if you wish to add sun time, as ascertained from an observation, to G. M. T., you must convert the former, L. A. T., into L. M. T. by applying the equation of time.

In some operations you must convert G. M. T. into G. A. T., which is also done by applying the equation.

Directions are given at the top of the column in the N. A. as to adding or subtracting the equation. If a black line is drawn across below the direction, look for a similar line in the equation column. If you add above the line, you subtract below, and *vice versa*.

The equation is subject, like declination, to hourly variation. This is found in the column to the right of the equation. It is applied to the equation precisely as the variation for declination is applied to it. If the time is after noon and the equation is increasing (which you can tell by inspection of the column), add the correction; if decreasing, subtract. Before noon reverse these processes.

*Example:* At sea, Feb. 27, 1882, chro-

nom. showed 4 hrs., 26 min., 15 sec. P.M. Required G. A. T.

| | | | |
|---|---|---|---|
| G. M. T.... | 4 h. 26 m. 15 s. P.M. | Hourly var. of equation... | 0.456″ |
| Cor. equat.. | 12 m. 55.9 s. | Time after noon.......... | 4.5 |
| G. A. T..... | 4 h. 13 m. 19.1 s. | | 2280 |
| | | | 1824 |
| | | | 2.0520″ |

| | |
|---|---|
| Equation.......... | 12 m. 53.92 s. |
| | 2.05 s. |
| Cor. equat.... | 12 m. 55.97 s. |

The student will observe that in making these corrections it is very convenient to use hours and decimal fractions of hours. Remember that 6 minutes are .1 of an hour; 6 sec. = .1 min. For instance, 4 hrs., 42 min. = 4.7 hrs.; 4 hrs., 15 min., = 4.25 hrs. In making the correction for declination it is not necessary to trouble yourself about a minute of time more or less. In correcting the equation, especially when you come to longitude observations, be accurate, for every second counts.

## LATITUDE BY MERIDIAN ALTITUDE

A meridian altitude is one taken when the celestial body observed bears true south or north of the observer, or is precisely above the meridian of longitude on

which he stands. In the case of the sun this is at apparent noon.

A meridian altitude gives the most accurate latitude, for reasons which will hereafter be explained.

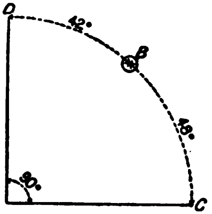
The general formula for a meridian altitude is lat. = zenith distance + or — declination.

Zenith distance is the distance, measured in degrees, from the point precisely over the observer's head to the observed body. Let us suppose that you and the sun are both north of the equator. If now you can ascertain exactly how far you are north of the sun, and how far the sun is north of the equator, you will, by adding the two measurements together, know your latitude.

The declination of the sun, obtained from the N. A. and corrected for chronom. time, as already explained, is the distance of the sun from the equator.

The zenith distance is the difference between the altitude of the sun, taken by the sextant, and 90°. You know that it is 90° from the zenith to the horizon. Hence, having got the altitude of the sun, you have only to subtract it from 90° to find

how far you are from the sun. The arc DBC in the diagram measures 90°. If the sun is at B, it is 48° from C, the horizon, and 42° from D, the zenith.




Now if you are 42° north of the sun, and it is 10° north of the equator, you must be 52° north of the equator, or in lat. 52° N.

That is the first and simplest case. Suppose, however, the sun is in south declination, and you are somewhere in north latitude. In that case your distance north of the equator would naturally be the zenith distance minus the declination, because the zenith distance, altitude, and declination together would make an arc of over 90°, and you can't be over 90° north or south of the equator.

Again, suppose that the sun is in 22° south declination, and you are 10° north of the sun. In that case you would have to subtract the zenith distance from the declination to get your latitude, because the sun's latitude is greater than yours. From

these considerations we deduce the following rule:

Begin to measure the altitude of the sun with the sextant a short time before noon. The altitude will constantly increase till apparent noon, when it will stop and then begin to decrease. You will be able to detect this by bringing down the image of the sun to the horizon in the horizon-glass and carefully watching it. The highest altitude attained is the one you need. At that instant note the chronometer time, and report 8 bells to the captain.

To work out the lat., call the altitude S. if the sun is south of you, N. if north. Correct the altitude for semi-diam., dip, and refraction as already explained. Subtract the true central alt. from 90° to obtain the zenith dist. If the alt. is S., name Z. D. north, or *vice versa*. Correct the declination for the chronom. time as already explained. If Z. D. and dec. are both N. or both S., add them, and the sum will be the lat. N. or S. as indicated. If one is N. and the other S., subtract the less from the greater, and the answer will be the lat. named N. or S. after the greater.

At sea, June 15, 1894. Observed merid. alt. ⊙, lower limb, 71° 15′ 00″ S. Index error, —47′; height of eye, 25 ft.; chronom. 3 hrs., 28 min., 15 sec. P.M.; chronom. slow of G. M. T. 1 min., 50 sec., on June 5. Daily rate, —.5 sec. Required lat. of ship.

| | |
|---|---|
| Obs. alt. ⊙ ..... | 71° 15′ 00″ S. |
| I. E. — .......... | 47′ 00″ |
| | 70° 28′ 00″ |
| Semi-diam....... | 16′ 00″ |
| | 70° 44′ 00″ |
| Dip............. | 4′ 54″ |
| | 70° 39′ 06″ |
| Refraction....... | 20″ |
| T. C. A.......... | 70° 38′ 46″ |
| | 90° 00′ 00″ |
| Z. D............. | 19° 21′ 14″ N. |
| Correct dec...... | 23° 20′ 20″ N. |
| Lat.............. | 42° 41′ 34″ N. |

| | |
|---|---|
| Chronom.... | 3 h. 28 m. 15 s. P.M. |
| Correction.. | 1 m. 55 s. |
| | 3 h. 30 m. 10 s. P.M. |
| Hourly var.......... | 6.14″ |
| Time after noon.... | 3.5 |
| | 3070 |
| | 1842 |
| Correction........ | 21.490″ |
| Dec................ | 23° 19′ 59″ N. |
| Correction......... | 21″ |
| Correct dec........ | 23° 20′ 20″ N. |

At sea, Sept. 25, 1894. Observed merid. alt. ⊙; lower limb, 50° 3′ 00″ S.; index error, +1° 14′; height of eye, 20 ft.; chronom. 2 hrs., 15 min., 10 sec. P.M.; chronom. slow of G. M. T. on Sept. 20, 1 min., 10 sec.; daily rate, —.3 sec. Required the lat. of ship.

| | |
|---|---|
| Obs. alt. ☉ | 50° 03′ 00″ S. |
| I. E. + | 1° 14′ 00″ |
| | 51° 17′ 00″ |
| Semi-diam | 16′ 00″ |
| | 51° 33′ 00″ |
| H. of E. cor | 4′ 23″ |
| | 51° 28′ 37″ |
| Refraction | 47″ |
| T. C. A | 51° 27′ 50″ |
| | 90° 00′ 00″ |
| Z. D | 38° 32′ 10″ N. |
| | 59′ 8″ S. |
| Lat | 37° 33′ 02″ N. |

| | |
|---|---|
| Chronom | 2 h. 15 m. 10 s. P.M. |
| Cor. for Sept. 25 | h. 1 m. 11.5 s. |
| G. M. T | 2 h. 16 m. 21.5 s. P.M. |
| Hourly var | 58.53″ |
| G. M. T | 2.25 |
| | 29265 |
| | 11706 |
| | 11706 |
| | 60) 131.6925″(2 m. 11 s. |
| | 120 |
| | 11 |
| Dec | 0° 56′ 57″ S. |
| Correction | 0° 2′ 11″ |
| Cor. dec | 59′ 08″ S. |

The operation can be shortened a little by making the corrections in a mass, using the refraction given for the observed alt., as shown in the remaining examples.

At sea, June 20, 1894. Observed merid. alt. ☉ 86° 29′ 45″ N. No index error; height of eye, 20 ft.; chronom. 10 hrs., 26 min., 30 sec. A.M.; chronom. fast of G. M. T. on date 3 min., 21 sec. Required lat. of ship.

| | |
|---|---|
| Semi-diam | 16′ 00″+ |
| Dip | 4′ 23″− |
| Refraction | 4″− |
| Correction | 11′ 33″+ |
| | |
| Obs. alt. | 86° 29′ 45″ N. |
| Cor | 11′ 33″ |
| T. C. A | 86° 41′ 18″ N. |
| | 90° 00′ 00″ |
| Z. D | 3° 18′ 42″ S. |
| Cor. dec. | 23° 27′ 05.8″ N. |
| Lat | 20° 08′ 23.8″ N. |

| | |
|---|---|
| Hourly var | 0.99″ |
| Time before noon | 1.4 |
| | 396 |
| | 99 |
| Correction | 1.386″ |
| Dec | 23° 27′ 07.1″ N. |
| Cor. | 1.3″ |
| Cor. dec. | 23° 27′ 05.8″ N. |

In actual sea practice so small a correction as 1.3″ would not be applied to the dec., because it has no effect on the resulting lat. It would be necessary in establishing a geographical location, such as that of a light. Working to tenths of seconds is also rarely necessary in lat. problems. Lat. is generally expressed simply in degrees and minutes, because at sea it is sufficient to know your position within a mile. The preceding problem, in practice, would be worked thus:

| | |
|---|---|
| Semi-diam. | 16′ 00″ |
| Dip. | 4′ 23″ |
| Refraction | 4″ |
| Correction. | 11′ 33″ |

| | |
|---|---|
| Obs. alt | 86° 29¾′ N. |
| Correction. | 11½′ |
| T. C. A. | 86° 41¼′ |
| | 90° 00′ |
| Z. D | 3° 18¾′ S. |
| Dec. | 23° 27′ N. |
| Lat | 20° 08¼′ N. |

The difference between ¼ minute (15″) and 23″ is of no account at sea. Hence, when the chronom. time from noon and the hourly variation of the dec. are both small, no correction need be applied to the dec. If either one or the other is large, al-

ways apply the error. Many licensed masters *never* apply it. Do not follow any such leaders, or you will some day land on a rock which you think is six or eight miles north or south of you. When approaching the land carry out your work to fractions; you cannot then be too accurate.

Another popular folly with merchant skippers and yacht captains is to regard the correction to the alt. as a *constant* quantity of 12′+. Instead of adding it to the alt. and then subtracting the sum from 90°, they make a short cut and subtract the 12′ from 90°, getting a constant of 89° 48′, from which they always subtract the alt. They would work the last example thus:

| | |
|---|---|
| Constant | 89° 48′ |
| Obs. alt | 86° 29¾′ |
| Z. D | 3° 18¼′ |
| Dec | 23° 27′ |
| Lat | 20° 08¾′ N. |

That looks short and easy, and the difference is only ⅓ mile. But let us take another case. On Dec. 20, 1894, your obs. merid. alt. was 11° 34′ 00″ S.; no index error; height of eye, 30 ft.; chronom. 11 hrs., 00′ 00″ A.M.

**Right way**

| | |
|---|---|
| Semi-diam. . . | 16′ 00″ + |
| Dip. . . . . . . . | 5′ 22″ − |
| Refraction . . . | 4′ 36″ − |
| Correction. . . . | 6′ 02″ + |

| | |
|---|---|
| Obs. alt. ☉. . . | 11° 34′ S. |
| Correction. . . . | 6′ + |
| T. C. A . . . . . . | 11° 40′ |
| | 90° 00′ |
| Z. D. . . . . . . . . | 78° 20′ N. |
| Dec. . . . . . . . . . | 23° 26¾′ S. |
| Lat . . . . . . . . . . | 54° 53¼′ N. |

**Wrong way**

| | |
|---|---|
| Constant . . | 89° 48′ |
| Obs. alt . . . | 11° 34′ S. |
| Z. D. . . . . . | 78° 14′ N. |
| Dec. . . . . . . | 23° 26¾′ S. |
| Lat. . . . . . . | 54° 47¼′ |

The student will note that the 89° 48′ puts the latitude 6′ in error; and it fails just at the time when accuracy is most needed—in winter. The cause of the error is the failure to allow for dip and refraction.

## LATITUDE BY MERIDIAN ALTITUDE OF A STAR

The student should purchase a set of simple star maps, and acquaint himself with the location of the principal fixed stars. Having learned to know the stars, he should practise assiduously at taking their altitudes. The best hours for observation are morning and evening twilights, when the horizon is clearly defined,

Moonlight nights also bring out a good horizon. With practice and a *first-class sextant*, fitted with a star telescope and well-silvered mirrors, the student will in time learn to "shoot" stars on any clear starlight night.

It is of inestimable value to know how to use the stars. The sun may be overclouded at noon—or all day—and at dusk there may be a star on your meridian to give you the latitude. You can find stars on the meridian at various hours of the night, and, the altitude once secured, the rest is even easier than working out lat. from the sun.

The declinations of all the stars available for the navigator are to be found in the back part of the N. A., in the star tables. Those marked + are N., those — are S. The *annual* variation of declination is so small that the dec. is not corrected; hence the chronometer time is not taken, and no allowance has to be made for semi-diameter. With these exceptions the method of working out the lat. by a star's merid. alt. is the same as that for the sun. You can tell when the star is approaching the meridian by its bearing.

*Example:* At sea, Dec. 7, 1894. At 10.50 P.M. took merid. alt. * Aldebaran (α Tauri) 75° 21′ 00″ S; no index error; height of eye, 20 ft.

| | |
|---|---|
| Obs. alt. * | 75° 21′ 00″ S. |
| Cor. | 4′ 38″ |
| T. C. A. | 75° 16′ 22″ |
| | 90° 00′ 00″ |
| Z. D. | 14° 43′ 38″ N. |
| Dec. | 16° 17′ 45″ N. |
| Lat. | 31° 01′ 23″ N. |

| | |
|---|---|
| Dip | 4′ 23″ |
| Ref. | 15″ |
| Correction | 4′ 38″ |

Nothing in the shape of a calculation could be much simpler than that. The practical part of the operation can be simplified, however, by knowing one or two additional facts. In the first place, you need to know how to find out what star you can use at a particular hour. For this you must employ the right ascension of the sun and the right ascension of the star required. The meaning of the term right ascension, designated R. A., will be explained later. The R. A. of the sun is to be found on the same page as the dec. in the N. A. The R. A. of the star is to be taken from the star table.

Subtract the sun's R. A. from that of the star. If the latter is the smaller, add

24 hours to it. The remainder will be the time of the star's meridian passage.

To know which star will cross the meridian after a certain hour, add that hour to the sun's R. A. The sum will be the R. A. of your own meridian. If it is more than 24 hours, subtract 24 hours from it. The star table will then show you what star's R. A. is equal to or a little greater than your own. That will be the next star to cross your meridian. If you are sailing to the eastward, it will cross a little ahead of time; if you are going west, it will be a little behind.

The next thing to do is to set your sextant at about the altitude the star will attain at its meridian passage, and at the proper time direct your instrument toward the south or north point of the horizon. The image of the star will at once appear in the horizon-glass, and you will have only a few minutes of watching for the merid. alt.

To calculate a merid. alt. subtract your lat. by D. R. from 90°. Call the remainder co-lat., and mark it N. or S. the same as the lat. If the co-lat. and the dec. are of the same name, add them; if of different names, subtract. The result is the approximate merid. alt.

*Example:* At sea, Aug. 29, 1894. Desired to correct the lat. by D. R. by a star merid. at 9 P.M.

| | |
|---|---|
| R. A. ⊙ ........ | 10 h. 31 m. 30 s. |
| Time at ship..... | 9 h. 00 m. 00 s. |
| R. A. Meridian.. | 19 h. 31 m. 30 s. |
| R. A. ✱ Altair... | 19 h. 45 m. 36 s. by star table. |

| | |
|---|---|
| R. A. Altair........... | 19 h. 45 m. 36 s. |
| R. A. Sun............. | 10 h. 31 m. 30 s. |
| Time of ✱'s merid. alt.. | 9 h. 14 m. 06 s. |

| | |
|---|---|
| Lat. by D. R............ | 45° 38′ 00″ N. |
| | 90° 00′ 00″ |
| Co-lat.................... | 44° 22′ 00″ N. |
| Dec. Altair.............. | 8° 35′ 18″ N. |
| Approx. merid. alt........ | 52° 57′ 18″ |

You will know whether the star is north or south of you by its dec. If you are in north lat., the star will be S. of you if its dec. is S., or if its dec. is north and less than your lat. If its dec. and your lat. are both N., and the former is the greater, the star will be north of you. The same principle applies if you are in S. lat.

Captain Lecky notes that sometimes you can get two stars, one north and one south, almost at the same time. Always take advantage of such a chance, for it lessens the range of error to take the mean of two observations. Suppose one star gave lat. 48° 15′ N., and the other gave 48° 10′ N. The mean, 48° 12′ 30″ N, would ~~be pretty~~, nearly correct,

## LATITUDE BY MERIDIAN ALTITUDE OF A PLANET

The mean time of passing the meridian and the declinations of the planets are given in the N. A. in the latter part. The dec. has to be corrected in the case of a planet, as it changes quite rapidly. The almanac gives the dec. for each day of the month and the variation for one hour, as in the case of the sun. The remainder of the operation is the same as that for a star.

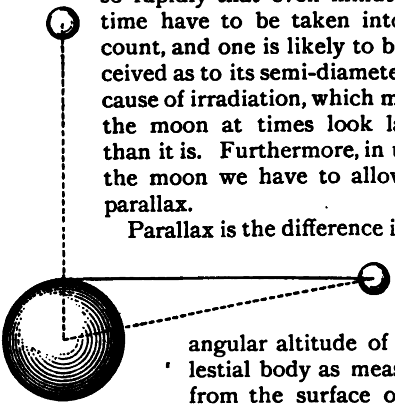
*Example:* At sea, Feb. 28, 1895. Obs. merid. alt. Saturn, 75° 21′ 00″ S.; no index error; height of eye, 20 ft.; G. M. T., 12 hrs., 5 min., 00 sec. A.M.

| | | | |
|---|---|---|---|
| Obs. alt. Sat.. | 75° 21′ 00″ S. | Dip..... | 4′ 23″ |
| | 4′ 38″ | Ref..... | 15″ |
| T. C. A....... | 75° 16′ 22″ | Cor..... | 4′ 38″ |
| | 90° 00′ 00″ | | |
| Z. D......... | 14° 43′ 38″ N. | | |
| Dec.......... | 11° 25′ 41.9″ S. | | |
| Lat.......... | 3° 17′ 56.1″ N. | | |

| | |
|---|---|
| Hourly diff. dec. Feb. 27.... | 1.60″ |
| Time after noon............. | 12 |
| Correction....... | 19.20″ |
| Dec. Feb. 27........ | 11° 26′ 01.1″ S. |
| Cor...... | 19.2″ |
| Cor. Dec.. | 11° 25′ 41.9″ S. |

## LATITUDE BY MERIDIAN ALTITUDE OF THE MOON

The moon is more or less of a nuisance, and is not used by expert navigators when it can be avoided. The declination changes so rapidly that even minutes of time have to be taken into account, and one is likely to be deceived as to its semi-diameter because of irradiation, which makes the moon at times look larger than it is. Furthermore, in using the moon we have to allow for parallax.



PARALLAX

Parallax is the difference in the angular altitude of a celestial body as measured from the surface or the centre of the earth. It is greatest when the body is in the horizon, and disappears when it is at the zenith. The sun is so far away that its parallax never exceeds 9″. The stars have practically none at all from the

earth's surface. The moon, however, is near enough to make an allowance necessary. Hence the rule for working out the moon's merid. alt. is as follows:

Find the G. M. T. of the moon's merid. passage in page iv. of the N. A. for the month. If you are west of Greenwich add the diff. for the number of hours west; if east, subtract. The hourly diff. is given under "Upper Transit." (How to tell the number of hours east or west will be explained under a subsequent heading.) Take the alt. in the usual way, and correct it for semi-diameter, dip, and refraction. Semi-diameter must be taken from page iv., N. A. Take the moon's parallax from p. iv., N. A., and correct it for hourly diff. With the corrected parallax enter Table XXIV., Bowditch, and take therefrom the correction to be *added* to the altitude. Find the dec. for the day and *hour* (G. M. T.) in pp. v.–xii. for the month, N. A., and correct for the number of minutes over the hour. Subtract the alt. from 90° to get Z. D., and apply the moon's corrected dec., according to rule given for sun, to get lat.

*Example:* At sea, May 1, 1895. Long. 45° W. = 3 hrs.; obs. merid. alt. of moon,

$30^{\circ}\ 15'\ 00''$ N.; I. E. (index error), $+20'$; H. of E. (height of eye), 30 ft.; chronom. time, 8 hrs., 58 min., 42 sec. P.M.; chronom. slow of G. M. T. 1 minute. (See table on next page.)

### MERIDIAN ALTITUDE BELOW THE POLE

It is frequently possible to get an altitude of a star when it is crossing the meridian below the pole. The north pole of the heavens is marked very closely by the polestar, which is never more than $1^{\circ}\ 20'$ distant from the pole. The stars in the northern part of the heavens apparently revolve around the pole, as may be plainly seen in the case of the constellation known as the "Dipper." When the given star is directly under the pole it is on the meridian, and will give the latitude just as correctly as when directly above it.

When in very high latitudes, where the sun does not set during six months of the year, the same thing may be done with the sun.

The rule is a simple one. It reads: polar distance + alt. = lat. Polar distance is the distance of a celestial body from the pole.

G. M. T. of merid. passage 8 h. 59 m. 42 s. P.M.

Dec. for May 1, 8 h.......21° 59′ 06.8″ N.
Correction................ 11′ 13″
Corrected dec............21° 47′ 53.8″ N.

Diff. for 1 minute..........11.280″
Minutes after the hour.....59.75

```
     56400
    78960
   101520
   56400
60 )673.98000″(11′ 13″
   660
    13
```

Obs. alt.......30° 15′ 00″ N.
Correction .... 9′ 07″
30° 24′ 07″
Cor. parallax .. 49′ 30″
T. C. A.......31° 13′ 37″
90° 00′ 00″
Z. D..........58° 46′ 23″ S.
Cor. dec.......21° 47′ 53.8″ N.
Lat ...........36° 58′ 29.2″ S.

Semi-diam...........16′ 08″
Dip................. 5′ 22″
Refraction.......... 1′ 39″
Correction...........9′ 07″

Parallax midnight ...59′ 10.8″
Correction for 3 h.... 1.5″
Cor. parallax.........59′ 09.3″
Cor. Table XXIV...49′ 30″

If the pole and the celestial body are in the same kind of lat., either north or south, you can find the P. D. by subtracting the body's declination from 90°. It is 90° from the pole to the equator. If, therefore, the body is 20° north of the equator, it is 70° south of the north pole. But from the south pole it would be $90° + 20° = 110°$. But you could not then get an alt. below the pole, because when in that position the body would be below your horizon. If you are in S. lat., you reckon polar distance from the south pole.

In taking an altitude below the pole, bear in mind that the altitudes continually decrease, and that the *lowest* is the merid. alt.

*Example:* Oct. 2, 1895, obs. alt. α Ursa Majoris (α of the Dipper), 8° 15′ 00″ N., bebelow pole; H. of E., 10 ft.; no I. E.

| | | | |
|---|---|---|---|
| Obs. alt. ✱ ... | 8° 15′ 00″ | Dip...... | 3′ 06″ |
| Cor .......... | 9′ 28″ | Ref...... | 6′ 22″ |
| T. C. A ...... | 8° 05′ 32″ | Cor...... | 9′ 28″ |
| P. D ......... | 27° 40′ 56″ | | |
| Lat .......... | 35° 46′ 28″ N. | | |

| | |
|---|---|
| Dec ........... | 62° 19′ 04″ N. |
| | 90° 00′ 00″ |
| P. D........... | 27° 40′ 56″ |

To set a sextant for a merid. alt. below the pole, subtract the star's P. D. from the

lat. by D. R.; the remainder will be the approximate alt.

### LATITUDE BY EX-MERIDIAN ALTITUDE OF THE SUN

Before proceeding further the student should learn how to convert longitude into time and time into longitude. The former operation will enter into most of the calculations yet to come, and the latter is always part of longitude workings.

The conversion is based on the fact that the sun takes 24 hours to pass around the 360° of the earth's circumference. Divide 360 by 24 and you get the number of degrees he passes in one hour, viz., 15°. Hence 15° of long. = 1 hour, and 1° = $\frac{1}{15}$ of 1 hour, or 4 minutes. Furthermore, 15′ of long. = 1 minute of time, and 1′ of long. = $\frac{1}{15}$ of 1 minute of time, or 4 seconds. Table VII., Bowditch, gives the various equalizations up to 360°, but you should be able to do without it.

*To convert time into long.*—Multiply the hours by 15 to get degrees. Divide the minutes by 4, and add the quotient to the num-

ber of degrees. If any minutes are left over, multiply them by 15. Divide the seconds by 4, and add the quotient to the minutes. Finally multiply the remaining seconds by 15.

*Example:* Turn 4 hrs., 29 min., 38 sec. into long.

$$\begin{array}{r} 4 \\ \underline{15} \\ 60 \\ \underline{7} \\ 67^{\circ} \end{array} \qquad \begin{array}{l} 4)\,29\,(7^{\circ} \\ \quad\ \underline{28} \\ \quad\ \ 1 \times 15 = 15' \\ \qquad\qquad\quad \underline{9} \\ \qquad\qquad\ 24' \end{array} \qquad \begin{array}{l} 4)\,38\,(9' \\ \quad\ \underline{36} \\ \quad\ \ 2 \times 15 = 30'' \end{array}$$

*Ans.* $67^{\circ}\ 24'\ 30''$.

*To convert long. into time.*—Multiply each member of the quantity by 4 and divide by 60, adding any figures left over to the result obtained from the next number to the right.

*Example:* Turn $50^{\circ}\ 40'\ 15''$ into time.

$$\begin{array}{l} \quad\ \ 50^{\circ} \\ \quad\ \ \underline{\ \ 4}\ \ \text{h.} \\ 60)\,200\,(\,3 \\ \quad\ \ \underline{180} \\ \quad\ \ \ 20\ \text{m.} \end{array} \qquad \begin{array}{l} \quad\ \ 40' \\ \quad\ \ \underline{\ \ 4}\ \ \text{m.} \qquad \text{m.} \\ 60)\,160\,(\,2 + 20 = 22 \\ \quad\ \ \underline{120} \\ \quad\ \ \ 40\ \text{s.} \end{array} \qquad \begin{array}{l} \quad\ \ 15'' \\ \quad\ \ \underline{\ 4}\ \ \text{s.} \qquad \text{s.} \\ 60)\,60\,(\,1 + 40 = 41 \\ \quad\ \ \underline{60} \\ \quad\ \ 00 \end{array}$$

*Ans.* 3 hrs., 22 min., 41 sec.

It is from this convertibility of time into degrees and parts of degrees (and *vice versa*) that we get the expression hour-angle.

Hour-angle is the distance of a body east or west of the observer's meridian, expressed either in time or angle. Thus at 11 A.M. the sun's hour-angle is either 1

hour or 15° E., at 1.15 P.M. it is either 1 hour and 15 min. or 18° 45′ W.

Now we come to ex-meridian altitudes. Suppose that at 12 o'clock, apparent time, the sun is obscured by clouds, and you cannot get your meridian altitude, but five minutes later it is perfectly clear. It is possible, fortunately, to use it even then. In fact, you may work the ex-meridian problem from 13 minutes before till 13 minutes after noon, but you must know your longitude accurately.

If you know the longitude, you can compute the hour-angle, and if you know that, you can reduce the altitude to what it would be at noon by applying the rule that near the meridian the altitude varies as the square of the interval from noon. Table XXVI., Bowditch, gives the change of altitude in 1 minute, and Table XXVII. gives the squares of the intervals up to 13 minutes. If you know the interval, or hour-angle, all you have to do is to multiply the change for 1 minute by its square, and add the result to your T. C. A., which, either before or after precise noon, must be just that much too low. Hence we get this rule:

Take the chronom. time of the observa-

tion. Correct it for rate, as usual. Correct the chronom. time for long. by subtracting from it your long. expressed in time if long. is W., and adding if long. is E. Result is local mean time. Convert this into local apparent time by applying the corrected equation of time, as already explained. If the L. A. T. is more than 12 hours, the surplusage is the hour-angle west. If less, subtract it from 12 hours, and the remainder is the hour-angle east. Enter Table XXVI. with the dec. of the sun at the top, and the lat. by D. R. at the side, and take out the change of alt. for 1 minute. Enter Table XXVII. with the hour-angle, applying minutes at the top and seconds at the side, and multiply the number given by that obtained from Table XXVI. Mark the result seconds, and reduce to minutes if 60 or more. Add this to the T. C. A. to obtain the merid. alt. Subtract this from 90° to get Z. D., and apply the dec. to get the lat. as heretofore directed.

*Example:* At sea, July 11, 1895. Lat. by D. R. 50° 01′ 00″ N., long. 40° W. Obs. ex-merid. alt. ☉ 61° 45′ 30″. H. of E., 15 ft.; I. E., 4′—. Chronom. time (corrected) 2 hrs., 38 min., 00 sec. P.M.

| | |
|---|---|
| G. M. T....... | 2 h. 38 m. 00 s. P.M. |
| Long. W....... | 2 h. 40 m. 00 s. |
| L. M. T....... | 11 h. 58 m. 00 s. A.M. |
| Cor. equat ..... | 5 m. 13 s. |
| L. A. T....... | 11 h. 52 m. 47 s. |
| | 12 h. 00 m. 00 s. |
| H. A......... | 7 m. 13 s. E. |
| Table XXVII.... | 52.1 |
| Table XXVI..... | 2.5″ |
| | 2605 |
| | 1042 |
| 60 ) | 130.25″ ( 2′ 10″ |
| | 120 |
| | 10 |

| | |
|---|---|
| Hourly diff. equation .......... | .336 |
| Time from Gr. noon.......... | 2.5 |
| | 1680 |
| | 672 |
| | .8400 |
| Equation.............. | 5 m. 12.62 s. |
| Cor. equat.......... | 5 m. 13.4 s. |
| Hourly var. dec............. | 19.88″ |
| | 2.5 |
| | 9940 |
| | 3976 |
| | 49.700″ |
| Dec .............. | 22° 07′ 26.4″ N. |
| Cor. dec .......... | 22° 06′ 36.7″ N. |

| | |
|---|---|
| Obs. alt.......... | 61° 45′ 30″ |
| | 7′ 41″ |
| T. C. A........... | 61° 53′ 11″ |
| Correction........ | 2′ 10″ |
| Merid. alt ........ | 62° 55′ 21″ |
| | 90° 00′ 00″ |
| Z. D ............ | 27° 04′ 39″ N. |
| Dec............. | 22° 06′ 36″ N. |
| Lat ............. | 49° 11′ 15″ N. |

| | |
|---|---|
| S. D .... | 16′ 00″ |
| I. E..... | 4′ 00″ |
| Dip..... | 3′ 48″ |
| Ref..... | 31″ |
| Cor..... | 7′ 41″ |

With an interval of time not greater than *one hour* from noon, latitude may be computed from an ex-meridian altitude by what is called the $\phi'$ and $\phi''$ sight. To make the computation you must learn to use Table XLIV., Bowditch. As this table is constantly used in working longitude you must make yourself thoroughly familiar with it.

Table XLIV. contains the logarithmic sines, cosines, tangents, cotangents, secants, and cosecants for all angles up to 180°. If you have studied trigonometry, you will know what these terms mean. If you have not, you can use them just as well for the purposes of navigation. The top and bottom of a page of Table XLIV. look like the table on next page.

If the desired number of degrees be found at the top, the name, sine, cosine, etc., must also be found there, as in the cases of 18° and 161° in the example. If the number of degrees is at the bottom, the logarithmic name will be found there. The additional minutes must be found in the column M on the same side of the table as the required degrees, and the logarithms opposite to them. In apply-

| 18° | | | A | | A | B | | B | C | | C | 161° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M. | H. A.M. | H. P.M. | Sine | Diff. | Cosecant | Tangent | Diff. | Cotangent | Secant | Diff. | Cosine | M. |
| 0 | 9 36 00 | 2 24 00 | 9.48998 | 0 | 10.51002 | 9.51178 | 0 | 10.48822 | 10.02179 | 0 | 9.97821 | 60 |
| 1 | 9 35 52 | 24 8 | .49037 | 1 | .50963 | .51221 | 1 | .48779 | .02183 | 0 | .97817 | 59 |
| 2 | 35 44 | 24 16 | .49076 | 1 | .50924 | .51264 | 1 | .48736 | .02188 | 0 | .97812 | 58 |
| 3 | 35 26 | 24 32 | .49115 | 2 | .50885 | .51306 | 2 | .48694 | .02192 | 0 | .97808 | 57 |
| 59 | 9 28 8 | 2 31 52 | 9.51227 | 37 | 10.48773 | 9.53656 | 41 | 10.46344 | 10.02429 | 4 | 9.97571 | 1 |
| 60 | 28 00 | 32 00 | .51264 | 38 | .48736 | .53697 | 42 | .46303 | .02433 | 4 | .97567 | 0 |
| M. | H. P.M. | H. A.M. | Cosine | Diff. | Secant | Cotang't | Diff. | Tangent | Cosecant | Diff. | Sine | M. |
| 108° | | | A | | A | B | | B | C | | C | 71° |

| Seconds of time...... | | 1 s. | 2 s. | 3 s. | 4 s. | 5 s. | 6 s. | 7 s. |
|---|---|---|---|---|---|---|---|---|
| Prop. parts of col. | A | 5 | 9 | 14 | 19 | 24 | 28 | 33 |
| | B | 5 | 10 | 16 | 21 | 26 | 31 | 37 |
| | C | 1 | 1 | 2 | 2 | 3 | 3 | 4 |

ing the seconds of your angle choose the logarithm for the nearest minute. Thus, for logarithms of 10° 15′ 42″, go to 10° 16′.

The columns marked Hour A.M. and Hour P.M. contain the apparent time corresponding to the sines, cosines, etc. When you come to longitude, you will have to take out the time corresponding to sines. When the observation is taken before noon, you take the time out of the A.M. column; afternoon, from the P.M. Notice that they are reversed at the bottom of the page. This means that if your sine is in the column having the word "sine" at the top, you work from the top of the page down; if your sine is in the column with "sine" at the bottom, you read from the bottom of the page up.

The parts of the sines, etc., to the left of the decimal mark are called the indexes. If the index is 10, omit it in adding the figures. Thus, if you were required to add the secant of 18° 03′ to the cosine of 71°, you would have $10.02192 + 9.51264 = 9.53456$. To simplify calculations, omit the index 10 when taking out the logarithm in the first place.

The use of the proportional parts of the columns A, B, and C may be omitted until we come to chronometer sights. We are now ready to give the rule for the $\phi'$ and $\phi''$ sight.

Take the chronometer time of the observation, and compute the hour-angle of the sun as already explained. Convert the hour-angle to terms of degrees, minutes, and seconds. Add the secant of the hour-angle to the tangent of the corrected declination, and the sum will be the tangent of an arc, which take out and call it $\phi''$. Add the sine of the arc $\phi''$ to the cosecant of the corrected dec. and the sine of the T. C. A. The sum will be the cosine of an arc to be taken out and marked $\phi'$. The lat. of the ship (at the time of observation, not at noon) is either the sum or difference of $\phi'$ and $\phi''$. Use the value which comes nearest to the lat. by D. R.

*Example:* At sea, June 8, 1895. Position by D. R., lat. 28° 40′ N., long. 60° 15′ W. Obs. alt. of sun's lower limb, after noon, 78° 30′ 00″. G. M. T., 4 hrs., 44 min., 30 sec. P.M.; H. of E., 20 ft.

G. M.T......4 h. 44 m. 30 s.    Hourly diff. equation .481″
Long. W.....4 h. 01 m. 00 s.    4.7
L. M. T.....    43 m. 30 s.    3367    H. diff. dec....13.51″
Equation ....    53 s.    1924    4.7
L. A. T.....    44 m. 23 s. = 11° 05′ 45″    22.607″    9457
Equation....1 15    5404
53″    63.497″ = 1′ 03″

Obs. alt......78° 30′ 00″    S. D.....16′ 00″    Dec......22° 51′ 26″ N.
11′ 25″    Dip...... 4′ 23″    1′ 03″
T. C. A......78° 41′ 25″    Ref...... 12″    Cor. dec..22° 52′ 29″ N.
11′ 25″

H. A........11° 05′ 45″    sec............ .00820
Cor. dec.....22° 52′ 29″    tang..........9.62504    cosec........... .41021
Alt..........78° 41′ 25″..............................sin.............9.99147
$\phi''$ .........23° 15′ 00″    tang..........9.63324    sin .............9.59632
$\phi'$.......... 5° 30′ 00″..............................cosine...........9.99800
Lat.........28° 45′ 00″ N.

The advantage of this method is that it is independent of the lat. by D. R., which may be, and frequently is, much in error. The method can be used for all celestial bodies, as hereafter explained.

## LATITUDE BY THE POLESTAR

Before attacking the method of computing lat. by Polaris, the north star, the student may as well learn several more astronomical facts, some of which demand close study for their comprehension. He has learned the difference between mean and apparent time. He must now learn what astronomical time and right ascension are, and he may as well complete the list with sidereal time.

Astronomical time is reckoned from noon of one day to noon of the next, and hence the astronomical day corresponds to the 24 hours of a ship's run. The hours are counted from 1 to 24, so that 4 o'clock in the morning of Oct. 5 is astronomically 16 o'clock of Oct. 4.

Right ascension is practically celestial longitude. A place on the earth is located

by its latitude and longitude; a heavenly body by its declination and right ascension. But R. A., as it is indicated, is not measured in degrees and minutes, nor is it measured east and west. It is reckoned in hours and minutes all the way around the sky from west to east through 24 hours.

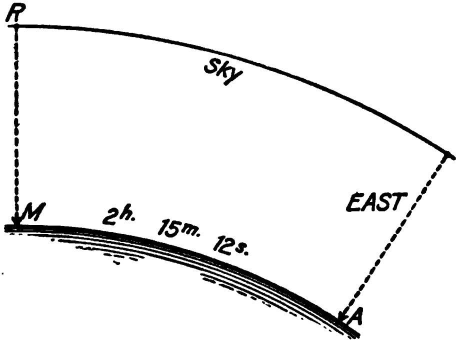
The celestial meridian from which this celestial longitude begins is not that of Greenwich, but it is that passing through the equator at the point where the sun crosses the line in the spring.

When we speak of a star as having a R. A. of 3 hrs., 42 min., 15 sec., we mean that any given spot on the surface of the earth will occupy 3 hrs., 42 min., 15 sec., in revolving from the prime meridian of celestial long. to the meridian of the star.

You will meet with the expression right ascension of the meridian. That means the R. A. of the meridian on which you are, and in many stellar observations you need to know it in order to compare it with the R. A. of the star.

It so happens that the R. A. of the meridian and local sidereal time are the same thing. Sidereal time is "star" time,

as opposed to solar or "sun" time. The sidereal day contains 24 hours, but it does not begin at midnight as the legal day does, nor at noon like the astronomical day. It begins when the prime celestial meridian (that at which celestial longitude commences) is right over the meridian on




which you stand. It is then what you might call sidereal noon at your place, just as it is solar noon when the sun is on the meridian.

Now suppose R. to be the prime celestial meridian, and M. your meridian. When M. is under R.. sidereal time at M. begins.

Also right ascension is measured eastward in hours and minutes from R. Now if M. occupies 2 hrs., 15 min., 12 sec. in revolving with the motion of the earth to A, when it arrives at A it will be 2 hrs., 15 min., 12 sec. o'clock sidereal time at M. And that must also be the R. A. of M., because R. A. is measured from the same point as sidereal time.

At present the student needs to learn only two things: first, how to find the sidereal time at Greenwich corresponding to any given hour of mean time there, and secondly, how to find the sidereal time corresponding to any given hour at his own meridian. It is obvious that if you can find the former, you can easily get the latter by applying the longitude of your meridian (converted into time).

A sidereal day measures in mean time—that is, by a chronometer or ordinary clock—23 hrs., 56 min., 04 sec. In other words, every hour, minute, and second in a sidereal day is a little shorter than its counterpart in a solar day. So, in turning mean time into sidereal time, we have to make some allowances. Tabie VIII., Bowditch, gives the allowances for changing sidereal

to mean time, and Table IX. for changing mean to sidereal. Similar tables are to be found in the N. A., back part.

The N. A. will give you the sidereal time at Greenwich noon for every day in the year. Hence the rule for converting G. M. T. into Greenwich sidereal time (G. S. T.) is this:

Add to G. M. T. the G. S. T. for the preceding noon, and the allowances given in Table IX. for the number of hours, minutes, and seconds in the G. M. T. If the sum is more than 24 hours, subtract 24 hours from it, because at the end of 24 hours Sid. T. begins over again.

*Example:* Required G. S. T., Nov. 2, 1895, when the G. M. T. by chronom. (corrected) was 7 hrs., 25 min., 15 sec.

| | | | |
|---|---|---|---|
| G. M. T ...................... | 7 h. | 25 m. | 15 s. |
| Sid. T. at G. at preceding noon.. | 14 h. | 46 m. | 1.9 s. |
| From table 7 hrs. 25 m.*....... | | 1 m. | 13.1 s. |
| Sid. T. at G.................... | 22 h. | 12 m. | 30.0 s. |

* The 15 seconds of G. M. T. are disregarded because the allowance is only .041".

Rule for finding S. T. at ship or R. A. M., when longitude is known: Find the mean time at ship by applying the longitude to the G. M. T. as previously explained.

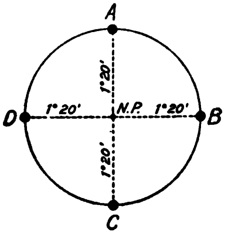
Add to mean time at ship the G. S. T. for the preceding noon and the allowances for the G. M. T. from Table VIII. If the result is over 24 hours, subtract 24 hours from it.

*Example:* Required the S. T. at ship Aug. 19, 1895, when the G. M. T. was 11 hrs., 15 min., 20 sec. P.M. Long. 60° 15′ W.

| | | |
|---|---|---|
| G. M. T. | 11 h. 15 m. 20 s. | |
| Long. W. | 4 h. 01 m. 00 s. | |
| M. T. at ship | 7 h. 14 m. 20 s. | |
| Sid. T. for preceding noon | 9 h. 50 m. 20.3 s. | |
| Allow. for 11 h. 15 m. | 1 m. 50.8 s. | |
| Sid. T. at ship | 17 h. 06 m. 31.1 s. | or Rt. Ascension of Meridian. |

All this is necessary here, because in order to work the lat. by the polestar you must use the R. A. M. In north latitudes the polestar is available at any hour of the night. This is because it apparently revolves around the north pole of the heavens at a distance of only 1° 20′, making the change of altitude so slow that it can be used always. Of course the star does not revolve around the pole at all. It is the earth that revolves. The student will remember what has been said about hour-angle. Now it is obvious that the H. A. of Polaris may be very great without

any serious change in the altitude. Let the centre of the circle be the north pole of the heavens, and the circumference the apparent orbit of Polaris. At D and B the altitude of the star equals the altitude of the pole, which equals the lat. For the north pole, being 90° from the equator, will be in the horizon of an observer at the equator. If




you go 10° north of the equator, your northerly horizon will drop by 10°, and hence the pole will be 10° high, and so on up to 90°, when the pole would be overhead, or 90° high. With the polestar at A you would have to subtract 1° 20′ from its altitude to get the altitude of the pole, which equals the lat.; at C you would have to add 1° 20′. Now as the R. A. of M. advances from 0 to 24 hours in exactly the same time as the polestar appears to revolve around the pole, the astronomers have made a table for us by which we can make the proper addition or subtraction

to the altitude of Polaris at any hour. What you have to do is to find the H. A. of Polaris, and in order to do that you must first get the S. T. at ship. Hence this is the rule:

Take the alt. and note the chronom. time at instant of observation. Correct the alt. as usual. Find the sidereal time at ship as already explained. If it is less than 1 hr., 20 min., subtract it from 1 hr., 20 min.; if it is between 1 hr., 20 min., and 13 hrs., 20 min., subtract 1 hr., 20 min. from it; if it is greater than 13 hrs., 20 min., subtract it from 25 hrs., 20 min. The remainder in each case is the H. A. of Polaris. Enter Table IV., on the last page of the N. A., with the H. A., and apply the correction there given as directed, either adding it to or subtracting it from the corrected alt. The result will be the lat.

*Example:* At sea, Dec. 20, 1895. Long. 45° 15′ W.; obs. alt. of Polaris, 40° 27′ 00″; no I. E.; H. of E., 20 ft.; G. M. T., 11 hrs., 30 min., 00 sec. P.M. (See table on next page.)

The chief difficulty in using Polaris, the student will find, is getting the altitude. The star is very small, and the northern

| | |
|---|---|
| Obs. alt. . . . . | 40° 27′ 00″ |
| | 5′ 31″ |
| T. C. A. . . . . | 40° 21′ 29″ |
| Correction. . . | 1° 12′ 00″ |
| Lat. . . . . . . . . | 39° 09′ 29″ N. |

| | |
|---|---|
| Dip . . . . . . . . | 4′ 23″ |
| Ref . . . . . . . . | 1′ 08″ |
| | 5′ 31″ |

| | |
|---|---|
| G. M. T. . . . . . . . . . . . . | 11 h. 30 m. 00 s. P.M. |
| Long. W . . . . . . . . . . . . | 3 h. 01 m. 00 s. |
| M. T. at ship . . . . . . . . | 8 h. 29 m. 00 s. |
| Sid. T. noon Dec. 20. | 17 h. 55 m. 16.7 s. |
| Allow. for 11 h. 30 m. . | 1 m. 53.3 s. |
| | 26 h. 26 m. 10 s. |
| | 24 h. 00 m. 00 s. |
| Sid. T. at ship. . . . . . . | 2 h. 26 m. 10 s. |
| Subtract. . . . . . . . . . . . . | 1 h. 20 m. |
| H. A. of Polaris . . . . . | 1 h. 06 m. 10 s. |

Correction from Table IV. = 1° 12′

part of the sea horizon not well illuminated; but it can be done after practice, and the star is always useful as a check on other observations.

It is now possible to explain how to work a $\phi'$ and $\phi''$ with a star or planet. You must find the hour-angle of the star, and that is always the difference between the R. A. of the star and the R. A. of your meridian. You will understand this at once if you have fully comprehended what R. A. is. And you will also understand that if the star's R. A. is less than yours, its H. A. is west; and if it is greater than yours, the H. A. is east. Always subtract the less from the greater, and mark the H. A. east or west according to this rule. You will need this point again in star time azimuths, to be explained presently.

How to find the R. A. M. has already been explained. The star's R. A. is got from the star table in the N. A. Having the H. A., proceed as in a $\phi'$ and $\phi''$ sight of the sun.

*Example:* At sea, June 6, 1880. Obs. alt. of star Altair, 50° 17′ 00″; no I. E.; H. of E., 22 ft., G. M. T., 4 hrs., 38 min., 09 sec. A.M. = 16 hrs., 38 min., 09 sec., astronom. time. Long. 23° 22′ W. Required lat. of ship.

| | | |
|---|---|---|
| G. M. T. ........... | 16 h. 38 m. 09 s. | Obs. alt. 50° 17′ 00″ |
| Long. W .......... | 1 h. 33 m. 40 s. | Cor .... 5′ 15″ |
| M. T. at ship...... | 15 h. 04 m. 29 s. | T. C. A. 50° 11′ 45″ |
| Sid. T. at G. at preceding noon .... | 4 h. 57 m. 09 s. | |
| Allow for G. M. T. | 2 m. 44 s. | |
| R. A. M .......... | 20 h. 04 m. 22 s. | |
| R. A. Altair....... | 19 h. 44 m. 59 s. | |
| Altair's H. A...... | 19 m. 23 s. = 4° 50′ 45″ | |

| | | |
|---|---|---|
| H. A.... 4° 50′ 45″ | sec... .00156 | |
| Dec..... 8° 35′ 00″ | tang..9.17880 | cosec... .82609 |
| T. C. A..50° 11′ 45″.................... | | sin.....9.88552 |
| φ″ ...... 8° 37′ 00″ | tang..9.18036 | sin.....9.17558 |
| φ′.......39° 32′ 00″.................... | | cosine..9.88719 |
| Lat......48° 09′ 00″ N. | | |

The above example is taken from Lecky, who works it by the Norie method, and gets 48° 08¾′ N. as his latitude.

### COMPASS ERROR BY AZIMUTHS

It is possible now to give the student further directions about finding the compass error by azimuths. The method was introduced under the head of "How to Find the Deviation." The student will see now that in employing the sun what he first requires is the sun's H. A. Hence, in taking an azimuth by the sun, the longitude being known, proceed thus:

Note the time of the azimuth by the chronom. Correct for rate. The result is G. M. T. Convert it into G. App. T. by applying the corrected equation. Convert G. A. T. into A. T. at ship by applying the longitude in time, subtracting it when west, adding it when east. The result is the A. T. at ship or local H. A. of the sun. Enter the azimuth tables with this and the corrected dec. to get the sun's true bearing.

*To take an azimuth by the moon, a planet, or a star.*—Note the time by chronom. Apply long. to get M. T. at ship. Proceed to find the H. A. of the celestial body as already directed. With this H. A. and the dec. get the true bearing from the azimuth tables.

## LONGITUDE BY CHRONOMETER (OR TIME) SIGHT

The foregoing methods of obtaining the lat. by observation are all that are of practical value at sea. The double - altitudes method is available in no instances where Sumner's problem (yet to come) is not bet-

ter, and Lecky's ex-meridians below the pole are very rarely of value. Hence we now come to the matter of longitude.

Since the sun revolves (apparently) around the earth once in 24 hours, passing through 15° of long. every hour, if we can ascertain how many hours and minutes east or west of Greenwich the sun is, and how many hours and minutes east or west of the sun we are, we shall know our long. When the long. is not known, then the problem is to find the local H. A. of the sun.

The H. A. from Greenwich we carry with us in the shape of the chronom., which tells us G. M. T., and that, of course, is simply the H. A. of the sun there. If we find the H. A. here—at our meridian—the difference between the two will be the number of hours, minutes, and seconds we are east or west of the Greenwich meridian, and this quantity is, as we have seen, convertible into the degrees, minutes, and seconds of longitude.

The computation of the H. A. of the sun is a complicated problem in spherical trigonometry; but the navigator has only to know how to use the tables prepared by

the astronomers and to employ simple arithmetic.

The necessary data are the T. C. A., the polar distance, and the latitude. At the instant of getting the altitude with the sextant, note the chronom. time accurately and correct it for rate. Make the corrections for dec. and equation of time according to the G. M. T. Then convert G. M. T. into G. App. T. by applying the corrected equation as directed by the N. A. You need G. App. T. because from your observation of the sun you get L. App. T. If you prefer, you can wait till you have computed that, and then convert it into L. M. T. so as to compare it with G. M. T. The first way is a little more convenient.

Take out the dec. for Greenwich noon, and correct it for hourly change just as in a lat. observation. If you are in N. lat. and the dec. is N., or in S. lat. and the dec. is S., subtract the corrected dec. from 90° to get the polar distance. If you are in N. lat. and dec. is S., or in S. lat. and dec. is N., add dec. to 90° to get P. D. The rule for the rest of the operation is this:

Add together the P. D., the lat., and the

T. C. A. Divide the sum by 2, and call the quotient the half-sum. From the half-sum subtract the T. C. A., and call the answer the difference. Now add the cosecant of the P. D., the secant of the lat., the cosine of the half-sum, and the sine of the difference obtained from Table XLIV. If the index of the sum is more than 9 (say 18), set it down so. Divide this sum by 2. The quotient is the sine of apparent time at the ship, which you are to take out of the A.M. column of Table XLIV. if the observation was an A.M. one, from the P.M. column if P.M. The difference between the App. T. at ship and G. App. T. is the long. of the ship in time, which turn into degrees, minutes, and seconds. If G. App. T. is greater than App. T. at ship, long. is west; if less, long. is east. Or, in the memorizing rhyme:

Greenwich time best,
Longitude west;
Greenwich time least,
Longitude east.

*Example* 1: At sea, Oct. 1, 1895. A.M. obs. alt. ☉ 17° 15′ 00″; G. M. T., 11 hrs., 30 min. A.M.; lat. 40° 30′ N.; H. of E., 15 ft.; I. E.—3′.

G. M. T. . . . . . . . . . . . 11 h. 30 m. 00 s.
Corrected equat. . . . 10 m. 16 s.
G. A. T. . . . . . . . . . . 11 h. 40 m. 16 s.

Hourly var. dec. . . . 58.25″
Time before noon. . 1.5
29125
5825
60) 87.375″ (1′ 27.3″
60
27

Obs. alt. . . . . . . 17° 15′ 00″
Cor . . . . . . . . . . . . . . 6′ 07″
T. C. A. . . . . . . 17° 21′ 07″

S. D . . . . . 16′ 00″
I. E. . . . . . 3′ 00″
Dip . . . . . . 3′ 48″
Ref . . . . . . 3′ 05″
Cor. . . . . . 6′ 07″

Polar dist. . . . . 93° 10′ 19″
Lat. . . . . . . . . . 40° 30′ 00″
Alt. . . . . . . . . . 17° 21′ 07″
2) 151° 01′ 26″
½ sum. . . . . . . . 75° 30′ 43″
Diff. . . . . . . . . . 58° 09′ 36″

cosec. . . . . . . .00066
sec. . . . . . . . . .11895

cos. . . . . . . . . 9.39811
sin. . . . . . . . . 9.92921
2) 19.44693
9.72346 = 7 h. 44 m. 34 s. S. A. T.
11 h. 40 m. 16 s. G. A. T.
Long. W. . . . . 58° 58′ 30″ = 3 h. 55 m. 42 s.

Hourly diff. equation. . . . . 0.801′
Time before noon. . . . . . . . 1.5
4005
801
Correction . . . . . . . . . . . . . 1.2015′

Equation. . . . . . . . . . . . . 10 m. 17.4 s
Cor. . . . . . . . . . . . . . . . . . 1.2
Cor. equat. . . . . . . . . . . . 10 m. 16.2 s

Dec. . . . . . . . . . . . . . . . . 3° 11′ 46.2″ S.
1′ 27.3″
Cor. dec. . . . . . . . . . . . . 3° 10′ 18.9″ S.
90° 00′ 00″
P. D. . . . . . . . . . . . . . . . 93° 10′ 18.9″

*Example* 2: At sea, Oct. 1, 1895. P.M. obs. alt. ☉ 20° 15′ 00″; G. M. T., 1 hr., 15 min. P.M., lat. 40° 30′ S.; H. of E., 15 ft. (See table on page 140.)

The student must now learn how to use the proportional parts of the columns A, B, and C, in Table XLIV. In the last example, for instance, the sine of App. T., 9.73435, is found exactly as it stands in the column of sines, and opposite it, in the P.M. column, are the hours, minutes, and seconds taken out. But suppose the sine had been 9.73421. This will not be found, for the next sine smaller than 9.73435 is 9.73416. In working long. you must be careful about the seconds, because 4 sec. of time = 1′ of long. Hence we proceed thus: Take the difference between the sine of App. T. and the sine nearest to it in the table. Apply the difference in the little table at the bottom of the page opposite the letter of the column from which the sine was taken. Above this will be found the number of seconds which must be added to or subtracted from the time given in the A.M. or P.M. column. If the sine of A. T. is larger than the sine in the table, add the difference obtained from the

G. M. T........ 1 h. 15 m. 00 s. P.M.
Cor. equat...... 10 m. 18.3 s.
G. A. T........ 1 h. 25 m. 18.3 s. P.M.

Dec............ 3° 11′ 46.2″ S.
Correction...... 1′ 09.9″
Cor. dec........ 3° 12′ 56.1″
90° 00′ 00″
P. D...........86° 47′ 04″

Obs. alt. ☾....... 20° 15′ 00″
9′ 43″
T. C. A........... 20° 24′ 43″

P. D......... 86° 47′ 04″
Lat........... 40° 30′ 00″
T. C. A...... 20° 24′ 43″
2) 147° 41′ 47″
½ sum....... 73° 50′ 53″
Diff........ 53° 26′ 10″

Hourly diff. equat....0.801″
1.2
1602
801
.9612

Equat...............10′ 17.4″
Cor. equat...........10′ 18.3″

Hourly diff. dec....58.25″
1.2
11650
5825
69.900″=1′ 9.9″

S. D........16′ 00″
Dip......... 3′ 48″
Ref......... 2′ 29″
Cor......... 9′ 43″

cosec....... .00068
sec......... .11895

cos......... 9.44428
sin......... 9.90480
2) 19.46871
9.73435 = 4 22 48 S. A. T.
1 25 18 G. A. T.
2 57 30 = Long..44° 22′ 30″ E.

little table to the given time; otherwise subtract it.

*Example:* Obtained sine of App. T. at ship, 9.73421. Difference between this and nearest sine in table, 5. Nearest sine being found in col. A, apply 5 in proportional parts of col. A, at bottom of page. Above 5 find 2 sec. Add 2 sec. to the time given for sine 9.73416, and you get the correct time for sine 9.73421, which is (P.M.) 4 hrs., 22 min., 42 sec.

### REMARKS ON LONGITUDE

As the lat. is best obtained when the sun bears due north or south, so the long. is most accurately found with the sun due east or west. This, however, you can rarely get, for to have the sun due east or west of you, your lat. and the dec. of the sun must be the same. If the sun rose due east every day and travelled across the sky due west, long. would be got just like lat. You know that it is just 90° from the horizon to the zenith, and you know that 90° is just a quarter of a circle. Now suppose the sun to be due east of you

when its alt. was 70°. By subtracting the alt. from 90° you would know that the sun had just 20° to pass through before crossing your meridian. In other words, its H. A. would be 20°, which = 1 hr., 20 min., and hence your App. T. would be 10 hrs., 40 min. A.M.

When the sun is due east or west of you it is said to be in the prime vertical (P. V.). But as the sun's dec. is almost invariably more or less than your lat., your observations for long. are nearly all ex-prime vertical. The farther away from the prime vertical the sun is, the more accurately you need to know your lat., while if the sun is on the P. V., an error of half a degree in the lat. will make no serious difference in the long. How valuable, then, are the stars, from which you can almost always select one which is nearly on the P. V., if not exactly so. In the North Atlantic in winter, when the sun is 20 odd degrees below the equator, far away from the P. V., the sky is full of bright stars whose declinations bring them well up towards the P. V.

The employment of stars in long. will be explained in the proper place. The

point to be urged here is this: Try to get the sun when it bears most nearly east or west of you. To ascertain at what time it will be so enter the azimuth tables with your lat. and the sun's dec. The tables give the true bearing of the sun for every 4 minutes of the day, and you can select the bearing which is nearest to E. or W., and take your observation at the time indicated. Do not fall into the common habit of the merchant marine of always taking the long. at the same hour. Select the right time and get good results.

### LONGITUDE BY SUNRISE AND SUNSET SIGHTS

The chronometer sight is the standard method. Sometimes, however, it is cloudy all day and the sun appears just at setting. The rule for sunrise or sunset sights is as follows:

Note the chronom. time when the sun's upper or lower limb touches the horizon. Correct the chronom. for rate. Correct the dec. as usual, and find the polar distance. Add the lat. and P. D., and from the sum

subtract 21′ if the lower limb was observed, or 53′ if the upper limb. Divide the answer by 2 to obtain the "half-sum," and add the 21 or 53 previously subtracted to obtain the "diff." Then proceed as in a chronom. sight, adding the cosec. of the P. D., sec. of the lat., cosine of the half-sum, and sine of the diff., and taking out App. T. at ship to compare with App. T. at Greenwich.

*Example:* Aug. 16, 1895. Lat. 48° 10′ N. Lower limb ⊙ touched horizon at 8 hrs., 30 min., 15 sec., by chronom., slow of G. M. T. 1 min., 15 sec. (See table on next page.)

This method is not often of value, and should be employed only when there is no chance of getting a chronometer sight of the sun or some other celestial body.

### CHRONOMETER SIGHT OF A STAR

The problem is to find the sidereal time at the ship, and compare it with the sidereal time at Greenwich. As there are 24 hours in a sidereal day, each hour equals 15° of longitude, as in solar time. Hence long. can be obtained as well from sidereal as from solar time. The rule is as follows;

G. M. T........ 8 h. 31 m. 30 s.
Cor. equat...... 4 m. 04 s.
G. App. T...... 8 h. 27 m. 26 s.

Hourly diff. equat..0.503″
8.5
2515
4024
4.2755

Equat..............4 m. 08 s.
Cor. equat .........4 m. 04 s.

Hourly diff. dec. 47.13″
8.5
23715
37944
.60 ) 403.155″ (6′ 43″
360
43

Dec......... 13° 45′ 07″ N.
Cor.......... 6′ 43″
Cor. dec..... 13° 38′ 24″
90° 00′ 00″
P. D........ 76° 21′ 36″ cosec...... .01241
Lat ......... 48° 10′ 00″ sec......... .17590
124° 31′ 36″
21′ 00″
2 ) 124° 10′ 36″
½-sum ...... 62° 05′ 18″ cos........ 9.67042
21′ 00″
Diff......... 62° 26′ 18″ sin........ 9.94767
2 ) 19.80640
9.90320 = 7 h. 05 m. 12 s. A. T. S.
8 h. 27 m. 26 s. G. A. T.
1 h. 22 m. 14 s. = 20° 33′ 30″ W. long.

Take the altitude and note the chronom. time as usual. Convert G. M. T. into G. Sid. T. as already explained. Find the hour-angle of the star by the use of the P. D., lat., and alt. in exactly the same way as for the sun—only *always* take the H. A. of a star, planet, or the moon from the P.M. col. of Table XLIV. If the H. A. is east (which you can tell by the bearing of the star), subtract it from the star's R. A.; if H. A. is west, add it to star's R. A. The result is the R. A. of your meridian, or sidereal time at ship, and the long. is the difference between it and the G. Sid. T. The rule is the same for the moon and the planets.

*Example:* Dec. 1, 1895. Obs. alt. of Sirius, 20° 10′ 00″. Chronom. 11 hrs., 15 min., 00 sec. P.M. Chronom. slow of G. M. T. 1 min., 26 sec.; no I. E.; H. of E., 20 ft.; lat. 38° 58′ N. (See table on next page.)

It is a good practice aboard ships provided with plenty of officers or well-instructed quartermasters, to make use of any hour-angle obtained from a chronometer sight for an azimuth. This is to be done by observing the compass bearing of the celestial body at the instant of taking

G. M. T............11 h. 16 m. 26 s. P.M.
Sid. T. at G. noon..16 h. 40 m. 22 s.
Allowance.........           1 m. 51 s.
                  27 h. 58 m. 39 s.
                  24 h. 00 m. 00 s.
Sid. T. at G........ 3 h. 58 m. 39 s.

Dec. Sirius... 16° 34′ 20″ S.
               90° 00′ 00″
P. D.........106° 34′ 20″

Obs. alt........20° 10′ 00″
Cor............        7′ 00″
T. C. A........20°  3′ 00″

Dip....4′ 23″
Ref....2′ 37″
       7′ 00″

P. D......106° 34′ 20″
Lat....... 38° 58′ 00″
T. C. A... 20° 03′ 00″
        2 ) 165° 35′ 20″
½-sum.... 82° 47′ 40″
Diff...... 62° 44′ 40″

cosec.... .01841
sec...... .10929

cos...... 9.09807
sin...... 9.94891
        2 ) 19.17469
            9.58734 = 3 h. 01 m. 59 s. H. A. East.
                      6 h. 40 m. 31 s. R. A. of Sirius.
                      3 h. 38 m. 32 s. Sid. T. at ship.
                      3 h. 58 m. 39 s. Sid. T. at G.
Long. 5° 01′ 45″ W. =      20 m. 07 s.

the altitude, and then getting the true bearing from the tables. In case of working with a star whose declination exceeds the 23° given in the table, the true bearing may be computed by the altitude-azimuth problem, in conjunction with a chronometer sight. The rule for this is as follows:

Add together the P. D., lat., and the T. C. A. Divide the sum by 2 and call the answer half-sum; take the difference between the half-sum and the P. D., and call the answer diff.

Add together the secant of the lat., the secant of the alt., the cosine of the half-sum, and the cosine of the diff. Half their sum is the cosine of half the angle of the true bearing, which must be doubled and reckoned from north in north lat., and from south in south lat.

*Example:* Take the time sight of Sirius, just used, and work it for the azimuth.

| | | | |
|---|---|---|---|
| P. D.. | 106° 34′ 00″ | | |
| Lat... | 38° 58′ 00″ | sec.... | .10929 |
| Alt... | 20° 03′ 00″ | sec.... | .02715 |
| 2) | 165° 35′ 20″ | | |
| ½-sum | 82° 47′ 40″ | cos.. | 9.09807 |
| Diff... | 23° 46′ 20″ | cos.. | 9.96151 |
| | | 2) | 19.19602 |
| | | cos.. | 9.59801 = 66° 39′ |
| | | | 2 |
| | | | N. 133° 18′ E. {true bear'g of Sirius. |

The beauty of this process is that the additional amount of work is so small. You already have the secant of the lat. and the cosine of the half-sum, and it takes only a few extra seconds to get the other two logarithms. You need never be in doubt as to which angle to select from Table XLIV. (which has two at the top and two at the bottom of the page), because the bearing must be less than 180°, and for a first-class longitude sight it ought to be as close to 90° as possible.

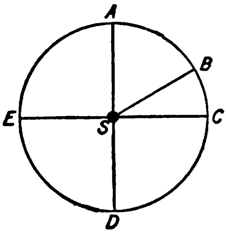
### SUMNER'S METHOD

We come now to the most valuable of all known methods of finding a ship's position at sea. Two or three makeshift methods of finding the longitude might have been explained; but this is a purely elementary and practical work, and it is deemed useless to introduce infrequent workings when by Sumner's method we can find, at almost any hour of the day or night, the latitude, longitude, and error of the compass by simply working two chronometer sights. Furthermore, we can

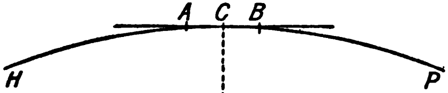
get a great deal of information from one sight.

Sumner's method is based on certain fundamental truths of navigation, which I shall now endeavor to explain, following pretty closely the admirable explanation of Captain Lecky.

Wherever the sun is, it must be perpendicularly above some spot on the surface of the earth. Suppose the sun to be immediately above the centre of the circle, S. Then if a man at A takes an altitude, he will get precisely the same one as men at B, C, D, and E, because they are all at equal distances from the sun, and hence on the circumference of a circle whose centre is S. Conversely, if several observers situated at different parts of the earth's surface take simultaneous altitudes, and these altitudes are all the same, then these observers must all be on the circumference of a circle, and *only one* circle. If you



moved one observer to the circumference of a larger circle, for instance, he would be

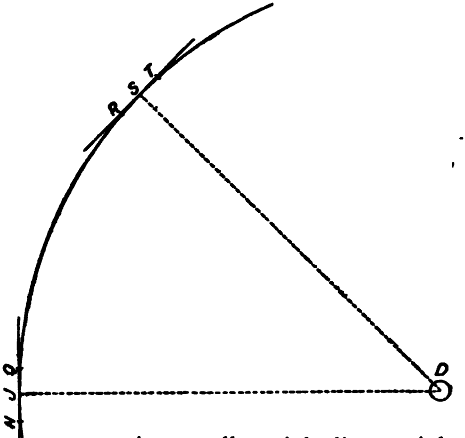



farther away from the sun and would get a smaller altitude.

Now such a circle on the surface of the earth would be very large — so large that a small arc of its circumference, say 20 or 30 miles, would be practically a straight line. Suppose D to be the point over which the sun is vertical, and HP to be part of the circumference of a circle drawn around this point. Suppose you were at C, and from an altitude of the sun you worked out your position. You would find yourself on the little arc AB, which to all intents and purposes is a straight line at *right angles to the true bearing of the sun from the point* C, as you may discern by simply looking at it.

Suppose now we continue the circle around D. Place an observer at J,

and let him take an altitude of the sun. He will be on the circumference of the same circle, but on the small arc QN, which is again practically a straight line and at right angles to the true bearing of the sun. At S he would find himself on the arc RT




—again a small straight line at right angles to the bearing of the sun.

If you draw any other circle, and mark points of observation, you will get similar results.

Hence: Any person taking an altitude of a celestial body must be, for all practical purposes, on a straight line which is at right angles to the true bearing of the body observed.

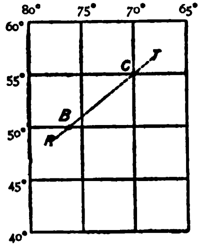
Such a line is called a Sumner line, or a line of position.

It must now be perfectly clear to the student that if the sun bears due north or south of the observer, the resulting line of position *must* run east and west; or, in other words, it is a parallel of lat. And that explains why a meridian observation gives the most accurate lat.

Again, if the sun bears due east or west the resulting line of position *must* run north and south; or, in other words, it is a meridian of longitude. And that explains why a prime vertical observation gives the most accurate longitude. The observer at J might be well over towards Q or N—in other words, mistaken considerably as to his latitude—but he would get his longitude all right.

But in the case of the man at S, the longitude cannot be known exactly unless the lat. is. Transfer the line to a chart. We know that we are somewhere on that

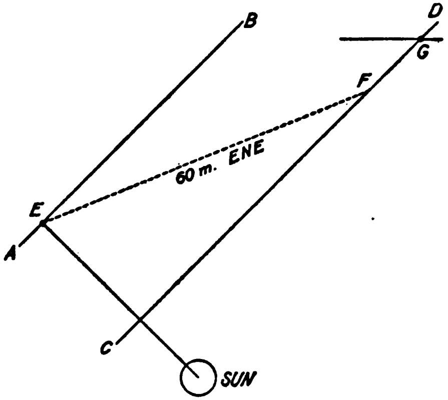
line RT. If the latitude is 50° N., we must be at the point where the line crosses the 50th parallel, which is at B. If the lat. is 55°, we must be at C. This shows how necessary the lat. is in cases where the observed body does not bear east or west. On the other hand, if you wished to get your lat. from the line RT, you would have to know your long. accurately. If the long. was 70° W., you would know you were at C.




Hence we get this operation from a single Sumner line: Whenever you take a chronometer sight of the sun, or any other heavenly body from the H. A., obtained in the computation, get the true bearing of the body from the azimuth tables, or by the alt.-azimuth problem. Then, through the position obtained, draw a Sumner line running at right angles to the true bearing.

You are absolutely sure to be somewhere on that line at the instant of observation; you cannot possibly be on any other.

Now suppose that you took the observation at 8 A.M., and that you were not quite sure of your lat. by D. R. From 8 A.M. till noon the ship sails 60 miles E.N.E., and then you get a meridian alt. and are sure of your lat. Through the point E, the 8



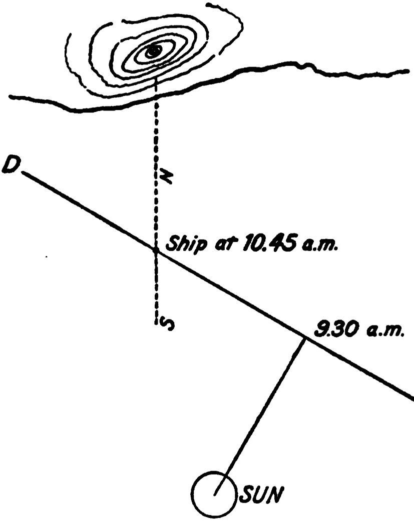

A.M. position, draw the Sumner line AB, at right angles to the sun's true bearing at 8 o'clock. From the point E lay off on the chart 60 miles E.N.E. on the line EF. At F, the extremity of EF, rule a new

Sumner line, exactly parallel to the old one. At the point G, where the parallel of your noon lat. cuts the Sumner line, is the position of the ship at noon.

The old, established way of making a noon position is this: Take your morning sight for long., but do not work it out. Take your noon sight for lat., and then by D. R. compute backward to the correct lat. at the time of the morning sight, and with this lat. work out the longitude. Then carry the longitude up to noon by D. R., and thus establish the lat. and long. at noon.

The method by a Sumner line and a parallel is far shorter and quite as accurate. By it you have found that you are on small arcs of two different circles at the same time. You can be *only* at their point of intersection. And that is the whole theory of the Sumner method.

The old-fashioned way of working a Sumner line is to assume two latitudes, say 25′ or 30′ apart, and about equally distant from the lat. by D. R., work out the chronometer sight with each, lay down the two different positions on the chart, and rule a line joining them. This will be your Sumner line. But why do all that when




one working-out is sufficient? Any position at all must be on a line at right angles to the sun's true bearing, and that's your Sumner line.

Suppose you are approaching a coast on which there is a high mountain visible 60 miles at sea. There are reefs off the coast. You are uncertain of your lat. within 6 or

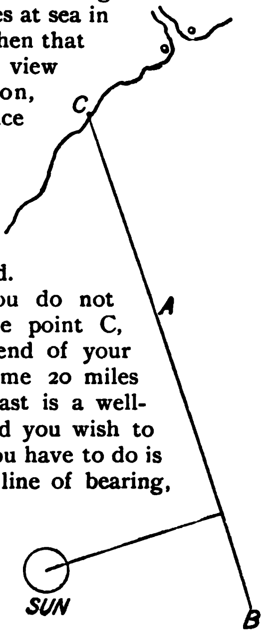
8 miles, but you fear you will reach the neighborhood of the reefs before noon.

At 9.30 you get a chronom. sight and draw the Sumner line CD. Put the ship on that line and sail on it. At 10.45 you sight the mountain bearing N. true. Draw a line running N. and S. true till it cuts your line of bearing. That is your position. The only thing in the world that could put you wrong in this instance would be a current, and you must guard against that by using the lead according to the method of sailing along a chain of soundings already explained.

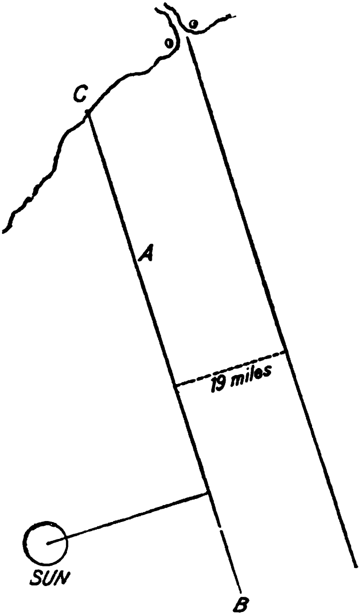
This introduces us to the excellent use of a single Sumner line when running in with the land. The simplest form of the operation is to take a chronometer sight and get a line of bearing. Suppose you are standing in towards a coast which you know to be northwest of you. Your position is not quite certain. You take a chronometer sight and get a position from which the sun bears W.S.W.¾W. You rule the Sumner line AB at right angles to it, running N.-by-W.¼W. Continue the line till it meets the land at the point C. Obviously if you sail on the Sumner line

heading N.-by-W.¼W. true, you will make the point C.

Suppose that at C there stood a well-known light-house, whose light was visible 18 miles at sea in clear weather. When that light popped into view over the horizon, you could at once verify your position by taking its bearing, and then sail in with boldness—not forgetting to use the lead.




But suppose you do not wish to make the point C, which is at the end of your Sumner line. Some 20 miles farther up the coast is a well-lighted harbor, and you wish to make that. All you have to do is to draw a second line of bearing, parallel to the first and ending at the point you wish to make. Measure the distance at




right angles between your two lines of bearing. Sail over that course and distance. You will then be on the second line of bearing, when you at once take the course N.-by-W.¼W. true, of the first line, and you are bound to make your harbor.

Let us see how this will work in practice. Suppose it to be late in the afternoon of a cloudy day in winter, and you are a little anxious because you have had no sights for longitude since 3 o'clock in the morning. Just before sundown the sun appears and you get a sunset sight.

Feb. 25, 1895. Lat. 30° 15′ N. The lower limb of the sun touched the horizon at 9 hrs., 32 min., 15 sec. by chronom. Chronom. fast of G. M. T. 3 min., 15 sec. Required a line of bearing.

G. M. T..9 h. 29 m. 00 s. P.M. Hourly diff. dec. 55.8″
Cor. equ.. 13 m. 10.8 s. Time after noon. 9½
G. A. T...9 h. 15 m. 49.2 s. 279

Dec........9° 04′ 19″ S. 5022
Cor........ 08′ 50″ 60)530.1″(8′ 50″
Cor. dec....8° 55′ 29″ S. 480

50

Cor. dec.. 8° 55′ 29″ S.
90° 00′ 00″
P. D..... 98° 55′ 29″ cosec. .00528
Lat....... 30° 15′ 00″ sec... .06357
Const.... 21′
2 ) 129° 10′ 29″
½-sum... 64° 24′ 44″ cos... 9.63531
21′
Diff...... 64° 45′ 44″ sin... 9.95645
2 ) 19.66061 h. m. s.
9.83030 = 5 40 36 A. T. S.
9 15 49 A. T. G.
Long....53° 48′ 15″ W = 3 35 13

By Table XXXIX. true bearing of sun = N. 100° W., or about W.-by-S. Sumner line will run N.-by-W.

If, now, you had land to the northward, your Sumner line would enable you to set a correct course to make it at the proper place. As a matter of fact lat. 30° 15′ N. and long. 41° 21′ W. are well to the southward and westward of the Azores; but the principle remains the same.

If so much can be done with a single Sumner line, how much more can be done with two. For if you can locate your ship on two Sumner lines at once, you know that she can be on but one place on either, and that is the point of intersection of both.

There are two ways of getting two Sumner lines, one by two successive observations of the same body, and the other by simultaneous observations of two bodies. The latter is, of course, preferable, but it is not available in the daytime.

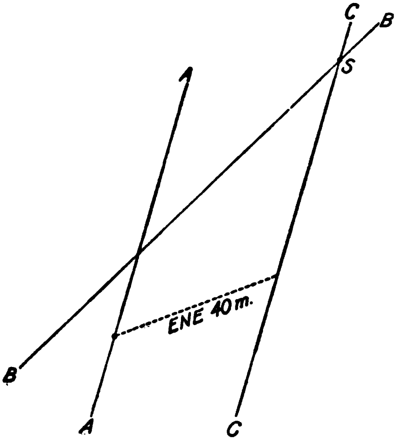
As applied to the sun the method is as follows: Take an observation, work it out with your lat. by D. R., and draw a Sumner line as already explained. Now wait till the sun's bearing alters at least 2 points. Take another observation and draw another Sumner line. It is obvious that it will make an angle of at least 2 points with the first one. The point of

intersection of the two lines is the position of the ship.

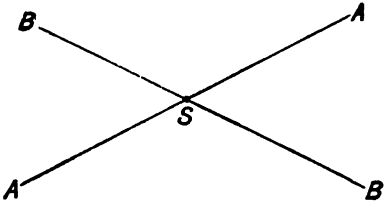
This, however, supposes the ship to be standing still. In practice she is making progress, and it becomes necessary to carry forward the first Sumner line to the place of the second observation. This is done by a process similar to that given for plotting a noon position.

Having taken your first sight and drawn your Sumner line, from *any* point on this line lay off the course and distance made up to the time of taking the second sight and drawing the second Sumner line. At the extremity of the course-line draw a third line parallel to the first Sumner line, and prolong it till it cuts the second Sumner line. The intersection of this parallel with the second Sumner line will be the position of the ship at the time of the second observation. For instance, suppose that in the diagram your first observation gave you the line of bearing AA, and your second the line BB. Between the two sights the ship sailed E.N.E. 40 miles. You lay off E.N.E. 40 miles from any point on AA, and draw CC parallel to AA. The intersection of CC and BB at S is the position of the

ship at the time of the second observation.




At night, however, you might get two stars, one east and the other west of you, and take observations of both so closely together as to be practically simultaneous. Then your easterly star would give the line AA and the westerly star the line BB, and you would be at S (as on p. 165).




### EXAMPLE OF SUMNER'S METHOD WITH THE SUN

At sea, June 1, 1895. Obs. alt. ⊙ 33° 50′ 00″; G. M. T., 8 hrs., 55 min., 00 sec. P.M.; H. of E., 20 ft.; no I. E.; lat. 40° 17′ N. (See table on page 166.)

Two hours later took another sight, which gave a corrected alt. of 11° 50′; G. M. T., 10 hrs., 55 min. Ship in the meantime made 12 m. N.-by-W.¾W. (See table on page 167.)

From azimuth tables true bearing of sun N. 69° 48′ W. or W.N.W.¼W. Sumner line, N.-by-E.¾E.

I have selected these positions because, owing to the high declination of the sun, its bearing alters only a point and a half in the two hours, and hence makes a bad "cut," as it is called, for the two Sumner lines. Yet see how plain it all is when

G. M. T........8 h. 55 m. 00 s.
Cor. equat......      2 m. 23 s.
G. A. T........8 h. 57 m. 23 s.

Dec........... 23° 03′ 55″ N.
                       03′ 03″
Cor. dec....... 23° 06′ 58″
                      90° 00′ 00″
P. D.......... 66° 53′ 02″   cosec.. .03635
Lat ........... 40° 17′ 00″   sec..... .11756
Alt............ 34° 00′ 11″
             2) 141° 10′ 13″
½-sum ........ 70° 35′ 06″   cos.... 9.52171
Diff........... 36° 34′ 55″   sin.... 9.77524
                                            2) 19.45086
                                                9.72543 = 4 h. 16 m. 48 s. A. T. S.
                                                                  8     57     23    A. T. G.
                                                                  4     40     35 = Long. 70° 08′ 45″ W.

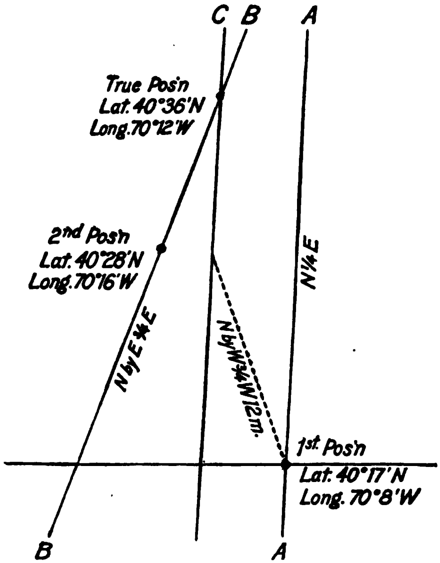
Hourly diff. equat....0.373
                                      9
                                  3.357′
Equat.........2     26.7
Cor. equat......2 m. 23.4 s.
Hourly diff. dec....20.39″
                                   9
                        60) 183.51″ (3′ 3.5″
                              180
                                  3

Obs. alt....33° 50′ 00″
                      10′ 11″
T. C. A....34° 00′ 11″

S. D...16′ 00″
Dip... 4′ 23″
Ref ... 1′ 26″
Cor ...10′ 11″

P. D. 66° 53′ 02″
Lat... 40° 17′ 00″   sec. .11756
Alt... 34° 00′ 11″   sec. .08143
       2) 141° 10′ 13″
½-sum 70° 35′ 06″   cos. 9.52171
Diff.. 3° 42′ 04″   cos. 9.99909
                              2) 19.71979
                                   9.85989 = 43° 36′
                                                         2
                                             N. 87° 12′ W. or W. ¾ N. = true bearing of sun. Sumner line [N. ¾ E.

| | | | | |
|---|---|---|---|---|
| G. M. T. ........ | 10 h. 55 m. 00 s. | | H. D. equat.... | 0.373″ |
| Cor. equat....... | 2 m. 22 s. | | | 11 |
| G. A. T ......... | 10 h. 57 m. 22 s. | | | 4.103 |
| | | | Equat ..........2 | 26.7 |
| | | | 2 | 22″ |
| Dec ............. | 23° 03′ 55.3″ N. | | H. D. dec ...... | 20.39 |
| | 3′ 44″ | | | 11 |
| Cor. dec ......... | 23° 07′ 39″ | | 60 ) | 224.29″ (3′ 44″ |
| | 90° 00′ 00″ | | | 180 |
| P. D ............ | 66° 52′ 21″ | cosec.... .03635 | | 44 |
| Lat ............. | 40° 28′ 00″ | sec...... .11874 | | |
| Alt ............. | 11° 50′ 00″ | | | |
| | 2 ) 119° 10′ 21″ | | | |
| ½-sum .......... | 59° 35′ 21″ | cos...... 9.70439 | | |
| Diff ............ | 47° 45′ 21″ | sin....... 9.86936 | | |
| | | 2 ) 19.72884 | h. m. s. | |
| | | 9.86442 = | 6 16 19 | A. T. S. |
| | | | 10 57 22 | A. T. G. |
| | | | 4 41 03 = | Long....... 70° 15′ 45″ W. |




drawn to a scale even smaller than that of a chart.

It appears from this that the latitude by D. R. was in error 8′ southerly. Yet, owing to the westerly bearing of the sun, the error in the longitude amounted to only 4′. Captain Lecky gives a table showing the error in longitude corresponding to an

error of 1′ in latitude at different bearings of the sun, and another showing the error for 1′ of altitude. They are most instructive. For the bearing of the sun in our second observation above he gives an error of .47 of a minute of long. for every error of 1′ in lat. For 8′ lat. this would make 3.76′ of long. which comes pretty near what we get from simply laying off the lines with a protractor and scale of equal parts. At sea, working on a chart, we should use the parallel rules (or protractor) and dividers.

The true bearing of the sun, required for the Sumner line, can always be used to get the deviation. Thus by this fine method we obtain from two sights the latitude, longitude, and error of compass.

In the above illustration the first bearing of the sun is worked out by the altitude-azimuth rule simply for illustration; in practice it would be taken, as the second is, from the azimuth tables.

Now let us see what can be done with two well-chosen stars. To make a good choice, get two stars whose bearings from the ship are as nearly at right angles as possible. This will bring the intersecting Sumner lines nearly at right angles and

make the position clearer. This computation, you see, is nothing more or less than astronomical cross-bearings.

## EXAMPLE OF SUMNER LINES WITH TWO STARS

At sea, Jan. 1, 1895. Obs. alt. Procyon 32° 44′ 00″ E., and *α* Arietis 58° 21′ 00″ W.; lat. by D. R. 39° 45′ N.; H. of E., 20 ft.; no I. E.; G. M. T., first observation, 12 hrs., 01 min. P.M.; second obs., 12 hrs., 02 min., 10 sec. P.M. Required position of ship by Sumner's method.

| | |
|---|---|
| G. M. T. .......... | 12 h. 01 m. 00 s. |
| Sid. T. at G. preceding noon.. | 18 h. 43 m. 32 s. |
| Allowance........ | 1 m. 58 s. |
| | 30 h. 46 m. 30 s. |
| | 24 h. |
| G. Sid. T. .......... | 6 h. 46 m. 30 s. |

| | |
|---|---|
| Dec. Procyon.... | 5° 29′ 37″ N. |
| | 90° 00′ 00″ |
| P. D. ........... | 84° 30′ 23″ |
| Obs. alt. Procyon... | 32° 44′ 00″ |
| Dip................ | 4′ 23″ |
| | 32° 39′ 37″ |
| Refr. ............. | 1′ 18″ |
| T. C. A. ........... | 32° 38′ 19″ |

| | | | |
|---|---|---|---|
| P. D. .... | 84° 30′ 23″ | cosec.. | .00200 |
| Lat...... | 39° 45′ 00″ | sec ... | .11416 |
| T. C. A.. | 32° 38′ 19″ | | |
| 2) | 157° 14′ 42″ | | |
| ½-sum... | 78° 26′ 51″ | cos.... | 9.30151 |
| Diff...... | 45° 48′ 32″ | sin .... | 9.85559 |
| | | 2) | 19.27326 |
| | | | 9.63663 = 3 h. 25 m. 20 s. H. A. East. |

True bearing of * N. 113° E.
Sumner line N. 23° E. or S. 23° W.

| | |
|---|---|
| 3 h. 25 m. 20 s. | H. A. East. |
| 7 h. 33 m. 48 s. | R.A. Procyon |
| 4 h. 08 m. 28 s. | Sid. T. at ship |
| 6 h. 46 m. 30 s. | Sid. T. at G. |

Long...39° 30′ 30″ W. = 2 h. 38 m, 02 s,

G. M. T. ................... 12 h. 02 m. 10 s. A.M  
Sid. T. G. preceding noon.. 18 h. 43 m. 32 s.  
Allowance................ 15 m. 8 s.  
30 h. 47 m. 40 s.  
24  
Sid. T. at G.............. 6 h. 47 m. 40 s.

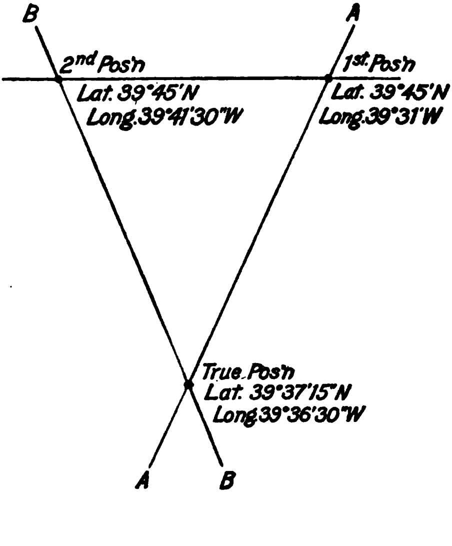
Dec. a Arietis.. 22° 57′ 56″ N.  
90° 00′ 00″  
P. D............ 67° 02′ 04″  
Obs. alt...... 58° 21′ 00″  
4′ 59″  
T. C. A...... 58° 16′ 01″

Dip.... 4′ 23″  
Ref.... 36″  
Cos.... 4′ 59″

P. D........... 67° 02′ 04″ cosec. .... .03587  
Lat............. 39° 45′ 01″ sec......... .11416  
T. C. A......... 58° 16′ 00″  
2 ) 165° 03′ 05″  
½-sum......... 82° 31′ 32″ cos......... 9.11474  
Diff............ 24° 15′ 32″ sin......... 9.61354  
2 ) 18.87831  
9.43915 = 2 h. 07 m. 39 s. H. A. West.  
2 h. 01 m. 15 s. R. A. *  
4 h. 08 m. 54 s. Sid. T. at ship.  
6 h. 47 m. 40 s. Sid. T. at G.  
Long... 39° 41′ 30″ W. = 2 h. 38 m. 46 s.

True bearing of * N. 112° W.  
Sumner line N. 22° W. or S. 22° E.

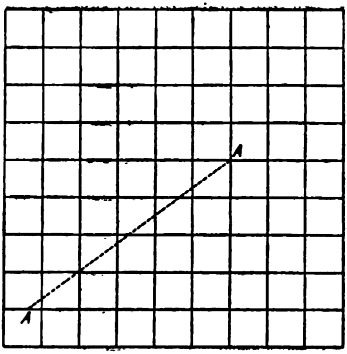
Plotted according to a scale of miles and with a protractor, the Sumner lines cut as below, making the true position lat. 39° 37′ N., long. 39° 36′ 30″ W. The lat. by D. R. was 7′ 45″ in error.

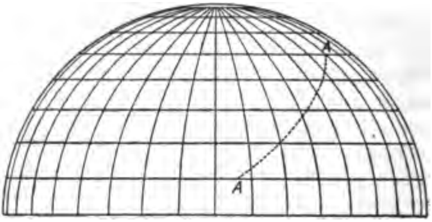


It is a peculiar fact that on a Mercator's chart a straight course between two places appears as a curve. This is owing to the expansion of the degrees of lat. and long. towards the poles, in order to construct the chart on the theory that the earth is a cylinder, as already explained. The converse is equally true: that a straight line ruled on a Mercator's chart is really a curve when you come to sail on it.

This is easily seen when you draw the two lines on flat or spherical surfaces. As the meridians of longitude constantly converge towards the poles, and as courses are all measured by the *angles they make with the meridians*, it naturally follows that when you draw the meridians all parallel to one another, you must be distorting an actual course when you make it cut all these meridians at the same angle. Drawn on a sphere, your straight course would become a curve, known as a rhumb line. (See page 174.)

Great-circle charts can be obtained, and on them all great-circle tracks appear as straight lines. But Sir George Airy, As-




tronomer Royal of Great Britain, designed a method of drawing a correct great-circle track on a Mercator's chart. His method is as follows:

Connect the point of departure and that of destination by a straight line, and find by measurement the centre of the line.

Draw from this central point, at right angles to the line first drawn, a second line, and continue it beyond the equator if necessary.

With the middle lat. between the two places enter the appended table, and take out the lat. under "corresponding parallel." The perpendicular line must reach and intersect this parallel.

Now put one point of the dividers in this intersection, and with the other point describe a curve which will pass through the point of departure and that of destination. This curve will be the great-circle track.

| Middle Lat. | Corresponding Parallel opposite Name to Lat. of Places | Middle Lat. | Corresponding Parallel same Name as Lat. of Places |
|---|---|---|---|
| 20° | 81° 13′ | * | * |
| 22° | 78° 16′ | * | * |
| 24° | 74° 59′ | * | * |
| 26° | 71° 26′ | * | * |
| 28° | 67° 38′ | 50° | 4° 00′ |
| 30° | 63° 37′ | 60° | 9° 15′ |
| 32° | 59° 25′ | 62° | 14° 32′ |
| 34° | 55° 05′ | 64° | 19° 50′ |
| 36° | 50° 36′ | 66° | 25° 09′ |
| 38° | 46° 00′ | 68° | 30° 30′ |
| 40° | 41° 18′ | 70° | 35° 52′ |
| 42° | 36° 31′ | 72° | 41° 14′ |
| 44° | 31° 38′ | 74° | 46° 37′ |
| 46° | 26° 42′ | 76° | 52° 01′ |
| 48° | 21° 42′ | 78° | 57° 25′ |
| 50° | 16° 39′ | 80° | 62° 51′ |
| 52° | 11° 33′ | * | * |
| 54° | 6° 24′ | * | * |
| 56° | 1° 13′ | * | * |

The blank spaces arise from the fact that in such relations great-circle sailing is of no advantage. Within the tropics, for instance, it is of little use, because the distortion of the degrees on a Mercator's chart is so small.

A ship on a great-circle track, except when on the equator or sailing N. or S. true, must change her course often in order to keep on the track. Here the principle that a small arc of a large circle on the earth's surface is practically a straight line may be employed, and the successive courses laid off as usual with parallel rules and dividers. You may find the distance on a great-circle course with close approximation by computing the lengths of these short courses and adding them.

To find the courses to be sailed, get the difference between the course at starting and that at the middle of the circle, and find how many quarter-points are contained in it. Divide the distance of half the great circle by this number of quarter-points, and that will give the number of miles to sail on each quarter-point course.

Suppose the course at starting to be N.E., and at the centre E.N.E., and the dis-

tance from start to centre 800 miles. The difference between N.E. and E.N.E. is 2 points, which = 8 quarter-points. Divide 800 by 8, and you get 100 miles for each quarter-point course. In other words, every 100 miles you change the true course a quarter of a point easterly.

Bear in mind that this means *true course.* Compass course must allow for variation and deviation.

*Accurate method of measuring the distance on a G.-C. track.*—Turn the largest course (always one of the end courses) into degrees. Then add the cosec. of the largest course, cosine of the smallest lat., and sine of the diff. of long. between the two places. Answer will be sine of the distance in degrees and minutes. As these are degrees and minutes of a great circle, which, like the equator, extends around the full circumference of the earth, multiply the degrees by 60 and add the minutes, and the result is the distance required.

If the sine of the distance gives more than 90°, subtract the angle from 180°, and use the sine of the remainder.

If near a coast, it is imperatively necessary that the navigator should have quick and certain methods of ascertaining his distance from well-marked points, and of avoiding hidden dangers set down on the chart.

When a light or a mountain first appears above the horizon, its bearing should at once be taken by compass, and the navigator should consult Table VI., Bowditch, which gives the distance at which elevated objects can be seen at sea. The height of the object when first seen above the horizon and the height of the observer must both be taken into account. Thus:

At sea, running for Block Island Channel, Block Island Light, 204 ft. above the level of the sea, appeared above the horizon. Observer on bridge 25 ft. above sea. Required distance of light.

| | | |
|---|---|---|
| Table VI..200 ft. | = 18.63 | miles' range of visibility. |
| " " .. 25 ft. | = 6.59 | " " " |
| | 25.22 | miles, distance of light. |

Uncommon refraction will sometimes make a light appear sooner than it ought to, and

the navigator must be on the lookout for such phenomena. In fact the whole operation is not to be accepted as infallible, for at the best it gives uncertain results.

The vertical angle of an object above the water-line, measured by the sextant, may also be used to give the distance. The navigator should possess Captain Lecky's *Danger Angle and Off-Shore Distance Tables*, in which are given the sextant angles for heights up to 1000 ft. The vertical angle can be used with these tables when the object is partly below the horizon, or when it is between the horizon and the observer. A handy set of vertical danger-angle tables is included in Captain Howard Patterson's *Navigator's Pocket Book*. If the object is far away, and the angle consequently very small, it should be measured both on and off the arc. For instance, with a light-house, first bring down the centre of the lantern (just as you would bring the sun) to the horizon, and read the angle. Then bring *up* the horizon line to the centre of the lantern by moving the index bar of the sextant towards you, and read that angle. Take the mean of the two, and enter the

tables under the height of the light. Opposite the sextant angle (or the nearest one to it) take out the distance. With a mountain bring down the top to the horizon. If the object is between you and the horizon, use the object's water-line.

*Example:* Oct. 5, 1894, bound west, passing Shinnecock Light, bearing N.-by-W.½ W. by compass, desired to know distance of ship from it. Vertical sextant angle, from centre of light to water-line, measured on and off, 22′ 45″.

In table under 160 ft. and opposite 22′ 50″, distance given is 4 miles.

Aboard U. S. men-of-war the Bradley Fiske range-finder may be used to find the distance of any object on shore not beyond its limits.

For passing concealed dangers the vertical sextant angle is used thus: Suppose that 300 yards to the eastward of a light 45 ft. high, which you must pass on the easterly side, lies a shoal spot or a reef dangerous to you. You therefore decide to pass 300 yards outside of it, or 600 yards from the light. Under 45 ft. and opposite 600 yards you find the angle 1° 26′. You set the sextant at that angle, and watch

for the image of the light in the horizon-glass. As long as the angle between the light and the water-line is 1° 26′ or *less*, you are 600 yards or more from the light. If the angle becomes more, you are inside of 600 yards. You need not move the index bar at all, for if the light rises above the water-line as seen in the horizon-glass, the angle is larger than that set, and in this case that means danger; but if it drops below, the angle is smaller.

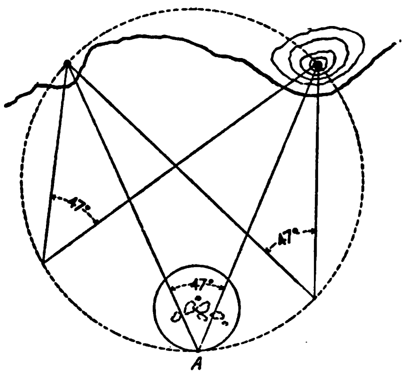
This same method of angling is used in keeping the distances between war-ships steaming in squadron. At night each ship carries a white light at her fore-truck, and the angular elevation of this light is watched. In daytime keep the truck itself at the water-line. The elevation of the mast is known. Ships in squadron always keep memoranda of the angles of their consorts for distance, half-distance, and double-distance. The masthead angle can also be used to set a target at a given distance from the ship.

The horizontal danger angle is at times extremely valuable, and the navigator should master its use. It is first necessary to learn to take horizontal angles with the

sextant. Hold the instrument face up. Look through the sight-vane and horizon-glass at the left-hand object, and push the index bar forward till the right-hand object makes contact with it. Then read the angle.

It is a good plan to take cross-bearings this way, noting the compass bearing of one of the objects. The bearing of the other is at once known by the angle between the two. If the ship's head should fall off between the bearings, and change the deviation, you would have only one deviation to apply.

The horizontal danger angle is used in passing hidden dangers. Suppose you wish to pass at a distance of a quarter of a mile outside of some hidden rocks, and on the shore are certain objects, say a light-house
church and a ~~mountain~~, marked on the chart. Draw a circle around the rocks with a radius of a quarter of a mile. Now describe another circle that will pass through the light-house, the church, and the most seaward part of your first circle. From this last point, A, draw lines to the light-house and the church. Now measure with a protractor the angle at the juncture of these




two lines. Set that angle (47° in the diagram) on the sextant, and watch the selected objects with instrument face up. The moment your two objects appear in the horizon-glass you are close to your circle of safety, and when they make contact you are on it. All you have to do is to alter the course of the ship so as to keep the contact, and so sail around the outer part of your circle till you have rounded the rocks. If you watch the angle closely this cannot fail, and in narrow waters it is an invaluable method.

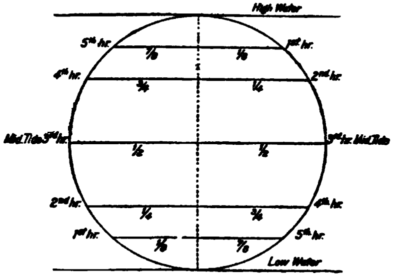
In measuring vertical danger angles get as close to the water as possible, so as to

remove error caused by your height above the water. This error, however, will increase your angle and thus place you farther away from the danger; so that you will be all right unless you have a second danger close aboard on the other side.

## ALLOWANCE FOR TIDES

In fixing positions by lights, mountains, etc., in passing over shoals, and in berthing ship at anchorage, bear in mind that *heights* are recorded on charts as measured from *high*-water, ordinary spring tides, while *soundings* are for *mean low*-water.

*To find the rise of the tide or its fall.*—Use the following diagram:



The right-hand side shows how the tide falls $= \frac{1}{8}$ of its range for the first hour, $\frac{1}{4}$ at the end of the second, $\frac{1}{2}$ at the end of the third, and so on. The left-hand side shows how it rises.

Remember that the rise and fall do not coincide with the change of tidal current. You must ascertain the duration of the ebb and flow from published sailing directions, such as the *Atlantic Coast Pilot.*

Where the range of the tide is great, you must allow for it in measuring angular altitudes of shore marks.

### KEEPING THE LOG

A log-book contains the record of the day's work of the ship. It may be made very simple or very elaborate. The ordinary merchant service log-book is quite simple. The data to be put in the book are noted on a log-slate by the watch officers and afterwards transferred to the log-book. A simple and satisfactory form of log is as follows:

| H. | K. | F. | Courses | Winds | Leeway | Remarks |
|---|---|---|---|---|---|---|
| 1 | 6 | | S.S.E.½E. | E.-by-N. | ¼ | Wind increasing till dog-watches; moderate thereafter. Fair weather. Smooth sea. |
| 2 | 6 | | | | | |
| 3 | 7 | 1 | | | | Stayed masts, set up rigging, and rattled down fore and aft. |
| 4 | 7 | 2 | ............ | ............ | .... | |
| 5 | 8 | | | | | |
| 6 | 8 | | | | | |
| 7 | 8 | | | | | |
| 8 | 7 | | | | | |
| 9 | 7 | | E.N.E. | S.E.-by-S. | ½ | Tacked ship. |
| 10 | 6 | | | | | |
| 11 | 6 | | | | | Alt. ✱ Altair E. of merid., 15° 44′ 40″. Chro. 2 h. 24 m. 56 s. A.M. Long. 16° 03′ 00″ W. |
| 12 | 6 | .... | ............ | ............ | .... | |
| 1 | 5 | | | | | |
| 2 | 5 | | | | | |
| 3 | 5 | | | | | |
| 4 | 5 | | | | | |
| 5 | 5 | 3 | E.-by-N. | S.S.E. | ¼ | |
| 6 | 5 | 6 | | | | Spoke bark *Pegasus*, Morton, master, bound west. |
| 7 | 6 | 2 | ............ | ............ | .... | |
| 8 | 6 | | | | | |
| 9 | 6 | 2 | | | | |
| 10 | 7 | 4 | | | | |
| 11 | 7 | | | | | Merid. alt. ⊙ 73° 39′ 20″ S. = Lat. 39° 35′ 56″ N. |
| 12 | 6 | 3 | ............ | ............ | .... | |

| Course made good | Dist. | Diff. lat. | Dep. | Latitude N. | | Diff. long. | Longitude W. | | Bearing and distance of port of destination at noon. Europa Point |
|---|---|---|---|---|---|---|---|---|---|
| | | | | D. R. | Obs. | | D. R. | Obs. | |
| E. 17° S. | 153′ | 44.4′ | 146′ | 39° 37′ | 39° 36′ | 191′ | 14° 21′ | 14° 03′ | S. 63° E. 592 miles. |

The hours, contained in the first column, are numbered from noon till noon. The second column contains the knots, and the third the fathoms, which are eighths of knots. The entries to be made in the remaining columns are perfectly apparent. Winds should never be entered in fractions, but in whole points.

The form of log used in the U. S. navy is exhaustive. The log is kept by the watch officers in a "rough-log" book, and afterwards copied in the official book by the ship's writer. Each officer signs that part of the log for which he is responsible with his full name and rank. Junior watch officers record the readings of the barometer and thermometers, state of weather, forms of clouds, proportion of clear sky, and condition of sea. (See table on next page.) Then follows the form for the remaining 12 hours, which is similar. These forms fill the left-hand page. The right-hand page is headed "Record of Miscellaneous Events of the Day," and contains the running record of the business and weather of each watch.

| Hour A.M. | Knots | Tenths | Courses Steered | Winds Direction | Winds Force | Leeway | Barometer | Temperature Air, Dry Bulb. | Temperature Air, Wet Bulb. | Temperature Water at Surface | State of the Weather by Symbols | Forms of Clouds by Symbols | Proportion of Clear Sky in Tenths | State of Sea | Record of Sail the Vessel is under at End of Watch |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 9 | 0 | N.E.-by-E. | N.W. | 6 | 0 | 30.14 | 58 | 53 | 61 | b. c. q. | cu. nimb. | 3 | S | None |
| 2 | 8 | 7 | " " | " | 6 | 0 | 30.14 | 58 | 53 | 61 | " " | " | 2 | S | |
| 3 | 9 | 0 | " " | " | 6–7 | 0 | 30.10 | 58 | 53 | 61 | " " | " | 5 | S | |
| 4 | 9 | 0 | " " | " | 6–7 | 0 | 30.10 | 58 | 53 | 61 | " " | " | 4 | S | |
| 5 | 9 | 0 | " " | " | 6–8 | 0 | 30.10 | 59 | 54 | 61 | " " | " | 3 | S | |
| 6 | 9 | 0 | " " | " | 6–8 | 0 | 30.10 | 59 | 54 | 61 | " " | " | 4 | S | |
| 7 | 8 | 7 | " " | " | 6 | 0 | 30.09 | 59 | 54 | 61 | " " | " | 6 | S | |
| 8 | 9 | 0 | " " | " | 6 | 0 | 30.09 | 59 | 54 | 61 | " " | " | 5 | S | |
| 9 | 10 | 0 | N.E.-by-N. | " | 5–6 | 0 | 30.09 | 60 | 55 | 62 | " " | " | 4 | S | |
| 10 | 10 | 0 | " " | " | 5 | 0 | 30.09 | 60 | 55 | 62 | " " | " | 5 | S | |
| 11 | 10 | 0 | " " | " | 5 | 0 | 30.09 | 61 | 56 | 62 | " " | " | 3 | S | |
| 12 | 10 | 0 | " " | " | 4–5 | 0 | 30.09 | 61 | 56 | 62 | " " | " | 0 | S | |

Distance run by log since preceding noon....
Latitude by D. R. at noon.................
Longitude by D. R. at noon.......... ....
Latitude by obs. at noon ⊙... ...........
Longitude by chronometer from forenoon observation ⊙...........................
Current ...............................

Var. of comp. by amplitude at sunrise........
Var. of comp. by azimuth observed at....h. ....m. ....s. ........................
Water expended in past 24 hours............
Water on hand fit for use at noon...........
Coal consumed during preceding 24 hours....
Coal on hand at noon .....................

## RATING A CHRONOMETER

It is sometimes necessary on a long voyage to ascertain the daily gain or loss of the chronometer, owing to the fact that the rate may be affected by extremes of temperature or other causes. The navigator may be far away from a maker, and hence must know how to ascertain the rate for himself. To perform the operation he will require an artificial horizon. This consists of a small trough, which is filled with absolutely clean mercury, and covered with a glass case which permits the observer to see the reflecting surface, and yet keeps wind and dust away from it.

The observer must now go with his sextant, chronometer, and artificial horizon to a spot where the longitude is accurately known to a fraction of a second. This will obviously be on shore, and that is why the artificial horizon must be used.

The observer should station himself, sitting, if possible, so that the artificial horizon will be in a direct line between himself and the body to be observed, and the image of the body will be shown in the mercury. Look through the sight-vane of

the sextant, so as to see the image in the mercury through the horizon-glass. Bring down the image reflected by the sextant mirror till it makes contact with the image in the mercury. At that instant note the chronom. time.

The angle of altitude shown by the sextant will be double what it would be with a sea horizon, and must therefore be divided by 2. The altitude is corrected as usual, except for height of the eye, which does not exist in this operation.

The remainder of the operation consists of finding the local mean time, and, by applying the longitude, the correct G. M. T. at the instant of observation. Thus the error of the chronom. is found. The observer now waits not less than six days (ten days are better), and then repeats the process at the same place. From the difference in the error on the two dates you get the daily rate.

For instance, suppose that on May 2, 1894, at Falmouth, Eng., you set out to rate your chronom. with artificial horizon and the sun. Your altitude, worked out according to the rule for a chronom. sight, gives you app. time at Falmouth 6 hrs., 53 min.,

22 sec. A.M. Apply the corrected equation of time and get Falmouth M. T., 6 hrs., 50 min., 07.8 sec. The longitude of Falmouth is 5° 02′ W. = 20 min., 08 sec. Add this to Falmouth M. T. and you get 7 hrs., 10 min., 15.8 sec. G. M. T. At the instant of observation the chronom. showed 7 hrs., 18 min., 18 sec. A.M.; chronom. fast of G. M. T., 8 min., 02.2 sec.

On May 8 you repeat the process, and find that the chronom. is 8 min., 05.2 sec. fast of G. M. T.

| | | |
|---|---|---|
| May 2............ | 8 m. 02.2 s. | |
| May 8............ | 8 05.2 | |
| Gain in 6 days.... | 3 s. | = Daily rate 0.5 s. |

Of course you can use the stars or planets for this work just as well as the sun. Whatever you use, bear in mind these facts: If the celestial body is rising (east of meridian), the two images seen through the horizon-glass will separate, provided you are using the lower limb. If the body is sinking (west of meridian), they will close.

Chronometers may be rated in many ports without observation by means of public time signals, such as time balls or guns, which mark a given hour either of local or G. M. T.

## CARE OF A CHRONOMETER

*(Condensed, by permission of T. S. and J. D. Negus, from their paper read before the Naval Institute)*

Be careful in carrying a chronometer never to give it a horizontal twist. This motion will affect the balance to such an extent as to throw the chronometer a second or a second and a half out of time.

The gimbals must be secured so as to prevent the chronometer from swinging while being carried. There is a stay for this purpose. Aboard ship the instrument should be allowed to swing.

Keep a chronometer aboard ship always in its outside case, in an apartment well ventilated, yet free from draughts. Never put a chronometer near wood which is in contact with salt-water.

Never open the outside case except when winding or taking time.

In damp countries wrap a blanket around the outside case.

You cannot do too much to protect a chronometer from rust. A small spot will change the rate of the instrument.

Wind the chronometer every day at the same hour, unless it is an eight-day chro-

nometer; then wind it once every week at the same time.

In winding, turn the chronometer bowl over in the gimbal slowly with the left hand, slide the valve by pressing the fore-fingers of the left hand against the nail-piece on the valve until the key-hole is uncovered, insert the winding key with the right hand, and wind to the left till a decided stop is felt. After removing the key, do not let the chronometer of its own accord drop to its level, but let it down carefully until horizontal.

Never let a chronometer get within the magnetic influence of a compass or an electro-magnet.

If a chronometer has run down and needs to be started, wait till the hands indicate the proper time, and then start it by a slight horizontal twist.

All chronometers reach their highest gaining or losing rate at a certain temperature. Those used in the United States Navy, made by Negus, reach their fastest rate at 70° F. Any exposure of the instrument to other temperatures will change the rate. The average temperature correction, as given by the makers, is .0025

second, multiplied by the square of the difference in the number of degrees of temperature. Thus, to find the correction to be made to the rate of a chronometer in a temperature of 80°, multiply .0025 by the square of the difference between 70° and 80°. A chronometer with a rate of +1 sec. at 70° would show the following variations:

| 55° | 60° | 65° | 70° |
|---|---|---|---|
| + .4375 s. | + .75 s. | + .9375 s. | + 1 s. |

| 75° | 80° | 85° |
|---|---|---|
| + .9375 s. | + .75 s. | + .4375 s. |

Chronometers should be cleaned and oiled at least once every three years and a half.

Vessels destined for long voyages should carry three chronometers. If you have two and one goes wrong, you cannot tell which is in error. With three you can make daily comparisons and know pretty well what they are doing.

Keep your chronometers away from iron. It affects the going of the instruments.

If you have to carry a chronometer, use the leather strap attached to the case, and be careful not to swing the instrument or let it knock against anything.

In transporting a chronometer overland (by rail, for instance), put it in a basket resting on plenty of cotton or some other substance that will keep it from jarring.

## HINTS ON CONDUCTING VOYAGES

Before leaving port ascertain the exact draught of your vessel. Also ascertain the height of your eye above the water-line at all points available for taking observations.

As soon as you are on open water fix the position of the ship by cross-bearings, by vertical or horizontal angle and compass bearing, or by compass and range-finder.

This is called taking departure, and is entered in the log opposite the hour thus: "Sandy Hook Lightship bearing S. 15° W., distant 2 miles, from which I take departure."

From the moment of taking departure begin the record of the course and distance for each hour in the log-book.

Enter the regulation noon position in the log every day; but get a "good fix,"

as it is called, at other times, especially in the mid and morning watches. If the sun fails to come to time the following morning and noon, you will be glad you shot the stars.

As soon as you take departure set the first course of your great circle, if on one, or your Mercator's course. If under sail, select the course which lies nearest to the great-circle track.

Work out your dead-reckoning traverse up to noon every day, and enter the results in the proper places in the log.

When approaching the land be keen to note every indication of its proximity. Look out for floating vegetation, change in the color of the water from sea blue to muddy green, flight of land birds, butterflies, etc.

Make it a cast-iron rule invariably to fix the ship's position by Sumner's method when approaching the land. If you can get a good line of bearing for your port—and you generally can—get on it and stay there.

As soon as you are on soundings start the sounding-machine or deep-sea lead going, and keep a record of the time of each

cast, with depth of water and character of bottom, and course and distance between casts, to compare with the chart. Many a first-class officer has lost his ship, his license, and his occupation from neglect to use the lead, and there is no hope for a man proved guilty of it before a court of inquiry.

Never attempt to pass close to hidden dangers when there are no landmarks near. Remember the history of the Roncador Reefs. Give such traps a wide berth.

As soon as land is sighted fix the position of the ship as often as possible by bearings and distances of mountains, lights, etc.

Remember that you can never be *too* sure of your position. Eternal vigilance is the price of safety at sea, and dangers increase with the approach to land.

Do not be discouraged if your first calculations are considerably abroad. Sir Thomas Brassey's first landfall was 60 miles in error; but he learned to take his yacht around the world. It takes time and practice to become an expert navigator, but any man of ordinary intelligence can be one if he perseveres.

## EXAMPLES FOR PRACTICE

### DEAD-RECKONING

Suppose a ship to sail upon the following courses and distances: S.E.-by-S., 29 miles; N.N.E., 10; E.S.E., 50; E.N.E., 50; S.S.E., 10; N.E.-by-N., 29; W., 25; S.S.E., 10; W.S.W.½W., 42; N., 110; E¾N., 62; N., 7; W., 62; N., 10; W., 8; S., 10; W., 62; S., 7; E.¾S., 62; S., 110; W.N.W.½W., 42; N.N.E., 10; and W., 25. Required the course and distance made good (Norie).

*Ans.* The ship has returned to the place she started from.

From lat. 40° 3′ N., long. 73° 28′ W., ship sails S.E.-by-S., 36 miles, variation ½ pt. west; S.E.-by-S., 8 miles, variation ¼ pt. west; S.E.½E., 28 miles, with half a point of leeway on the starboard tack and variation ¼ pt. west. Ship has been 8 hrs. in a current setting N.E. (variation ¼ pt. W.) at the rate of 2 knots per hr. Required lat. and long. in and course and distance made good (Patterson).

*Ans.* Lat. 39° 26′ N., long. 72° 07′ W., course S. 60° E., dist. 72 miles.

## SHAPING COURSE BY MERCATOR'S SAILING

Required the bearing and distance of Pernambuco, lat. 8° 4′ S., long. 34° 53′ W., from Cape Verde, lat. 14° 45′ N., long. 17° 32′ W. (Norie).

*Ans.* S. 37° W., dist. 1715 miles.

Required course and distance from Cape Palmas, lat. 4° 24′ N., long. 7° 46′ W., to St. Paul de Loando, lat. 8° 48′ S., long. 13° 8′ E. (Norie).

*Ans.* S. 58° E., dist. 1481 miles.

## LATITUDE BY MERIDIAN ALTITUDE OF SUN

At sea, merid. alt. ⊙ 38° 15′ 15″ S.; I. E., 1° 10′ —; H. of E., 15 ft.; chronom., 4 hrs., 10 min., 18 sec. P.M.; chronom. slow of G. M. T. 4 min., 37 sec.; dec., 15° 27′ 13″ N., increasing; hourly var., 44.6″. Required lat. of ship.

*Ans.* 68° 14′ N.

At sea, merid. alt. ⊙ 53° 52′ S.; I. E., —3′ 24″; H. of E., 24 ft.; G. M. T., 4 hrs., 54 min., 10 sec. P.M.; dec., 2° 47′ 3.5″ N., de-

creasing; hourly var., 57.9″. Required lat. of ship.

*Ans.* 38° 43′ N.

At sea, merid. alt. ☉ 48° 18′ 15″ N.; I. E., —2′ 15″; H. of E., 20 ft.; G. M. T., 10 hrs., 26 min., 15 sec. A.M.; dec., 19° 26′ S., decreasing; hourly var., 35.5″. Required lat. of ship.

*Ans.* 61° 17′ S.

At sea, merid. alt. ☉ 59° 45′ 45″ N.; I. E., + 30′ 15″; H. of E., 15 ft.; G. M. T., 6 hrs., 14 min., 20 sec. A.M.; dec., 4° 15′ 12″ N., increasing; hourly var., 58″.

*Ans.* 25° 22′ S.

## LATITUDE BY MERIDIAN ALTITUDE OF STAR

At sea, Dec. 24, 1894. Merid. alt. * Aldebaran 52° 36′ S.; no I. E.; H. of E., 20 ft.; dec. of * 16° 17′ 52″ N. Required lat. of ship.

*Ans.* 53° 47¾′ N.

At sea, Dec. 26, 1894. Merid. alt. Sirius 36° 28′ S.; I. E., — 45″; H. of E., 14 ft.; dec. of *, 16° 34′ 20″ S. Required lat. of ship.

*Ans.* 37° 3′ N.

## LATITUDE BY MERIDIAN ALTITUDE BELOW THE POLE

At sea, April 10, 1885. Merid. alt. * Canopus below pole, 22° 38′ S.; dec., 52° 37′ 59″ S.; I. E., + 2′; H. of E., 18 ft. Required lat. of ship (Sturdy).

*Ans.* 59° 55′ 39″ S.

At sea, June 18, 1885. Obs. merid. alt. ⊙ below pole, 8° 10′ 20″; dec. at time of obs., 23° 25′ 57″ N.; I. E., + 3′; H. of E., 20 ft. Required lat. of ship (Sturdy).

*Ans.* 74° 52′ N.

## LATITUDE BY EX-MERIDIAN ALTITUDES

At sea, July 12, 1885. Lat. by D. R. 50° N., long. by D. R. 40° W.; obs. ex-merid. alt. ⊙ 61° 48′ 30″; I. E., — 3′; dip, 3′ 48″; G. M. T. of obs., 2° 39′ 9″; dec. of ⊙ 21° 55′ 36″ N.; hourly diff. dec., 21.22″, dec. decreasing; equation of time to be subtracted from M. T., 5 min., 20.7 sec.; hourly diff. equation, .314″, equation decreasing. Required lat. of ship (Sturdy).

*Ans.* 49° 56′ N.

At sea, June 6, 1880. Lat. by D. R. 49°

21′ N., long. 18° 18′ W.; obs. ex-merid. alt. * Arcturus, 59° 41′ S.; dec. of * 19° 48′ 15″ N.; no I. E.; H. of E., 22 ft.; G. M. T., 9 hrs., 46 min.; G. Sid. T. preceding noon, 5 hrs., 1 min., 6 sec.; R. A. of * 14 hrs., 10 min., 14 sec. Required lat. of ship by $\phi'$ and $\phi''$ sight (Lecky).

*Ans.* 49° 23¼′ N.

### LATITUDE BY THE POLESTAR

At sea, June 21, 1880. Lat. by D. R. 45° 20′ N., long. 37° 57′ W.; obs. alt. of Polaris, 44° 13′ 30″ N.; I. E., + 30″; H. of E., 32 ft.; G. M. T., 11° 45′ 20″; G. Sid. T. preceding noon, 6 hrs., 14 sec. Required lat. of ship (Lecky).

*Ans.* 45° 17′ N.

### LONGITUDE BY CHRONOMETER SIGHT

Observed A.M. alt. ⊙ 20° 30′; chronom. 1 hr., 11 min., 19 sec. P.M.; chronom. 10 min., 20 sec. fast; H. of E., 10 ft.; lat. by D. R. 40° 15′ N.; dec. at noon, 13° 26′ 6″ S.; hourly diff. dec., 50.36″, dec. decreasing; equation of time, 14 min., 27.66 sec.;

hourly diff. equation, .055″, equation decreasing; equation to be added to app. time. Required long. of ship (Patterson).

*Ans.* 58° 59′ 45″ W.

At sea, Jan. 22, 1895. Obs. alt. of ⊙ A.M. 17° 14′; G. M. T., 11 hrs., 42 min. A.M.; H. of E., 20 ft.; no I. E.; lat. 38° 50′ N.; dec. at noon, 23° 33″ S.; hourly diff., 12.48′ dec. decreasing; equation of time (to be subtracted from mean time), 3 min., 46.42 sec.; hourly diff. equation, 1.183 sec., equation increasing. Required long. of ship.

*Ans.* Long. 34° 18′ 30″ W.

At sea, Feb. 27, 1882. Lat. 40° 10′ 45″ N.; H. of E., 30 ft.; no I. E.; obs. alt. * Procyon, 39° 11′ E.; G. M. T., 9 hrs., 58 min., 45 sec.; Sid. T. at G. at preceding noon, 22 hrs., 28 min., 52 sec.; dec. *, 5° 31′ 15″ N.; R. A. *, 7 hrs., 33 min., 10 sec. Required long. of ship, true bearing of star, and Sumner line (Lecky).

*Ans.* Long. 55° 40′ 15″ W.; true bearing of star, S. 58° E.; Sumner line, N. 32° E.

THE END